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THESIS

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OF AN IBM 360 COMPUTER

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June 1970

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Utilizing the Graphic Display

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ABSTRACT

A system for PERT analysis using Monte Carlo methods to estimate project completion times was designed using a 2250 Display Unit operating on an IBM 360/67 computer. The user enters the PERT network and the distributions of activity times by using the light pen on the 2250 Display Unit.

After the computer performs the analysis, the probability of being on the critical path is shown for each arc in the network and a histogram of project completion times is displayed. The user may then modify the network and run another analysis.

A discussion of the difference between this Monte Carlo PERT analysis and the usual PERT analysis and details of the implementation is included, along with operating instructions for the program. A user with no programming experience on the 2250 Display Unit can utilize the program by following the operating instructions.

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I. INTRODUCTION

PERT (Program Evaluation and Review Technique) is a technique for determining the expected time of completion and the variance associated with this expected time for a project involving a number of activities which are interrelated. The usual PERT analysis, described in ref. 1 and 2, involves analyzing the network once using expected activity durations and computing an expected completion time, a variance on this completion time, and a critical path.

A Monte Carlo analysis, discussed in ref. 3, involves analyzing the network a great many times using random numbers to draw activity duration times from the distribution of each activity's duration times. This method also computes an expected project completion time and a variance on this completion time. However, instead of a single critical path, a criticality index is calculated for each activity. This is the ratio of the number of times an arc was on the critical path to the total number of analyses.

A. STATEMENT OF THE PROBLEM

To analyze even a fairly simple PERT network by hand can be very time consuming. To analyze a network many times as is done in a Monte Carlo analysis would be a Herculean task if done by hand. At the same time, a student who is to be expected to use PERT networks in the future should know how a network is analyzed and have a good understanding of the meaning of critical path, criticality indexes, and the effects on these from changes to the network and the activity duration times. One way to accomplish these objectives is to combine the rapid

processing of the computer with a visual display which allows the student to experiment and change the network.

This paper describes a computer program, PERT-O-GRAPH, which allows a user to draw a PERT network by using a light pen on a graphic display unit. Distributions of activity duration times can be entered by drawing the distributions with the light pen or reading them from punched cards. A single analysis, called a "Mean Time Calculation" in this program, can be made which is similar to the usual PERT analysis. The user can then run an analysis using Monte Carlo techniques to estimate the distribution of project completion times. The program illustrates the changing of the critical path as activity durations vary, and the criticality indexes of each arc on the network after the analysis is complete.

PERT-O-GRAPH has been designed to operate on an IBM 360/67 computer with an IBM 2250 Display Unit Model 1. After reading this paper a user should be able to enter and analyze PERT networks even if he has no previous experience with the IBM 2250. No knowledge of computer programming techniques is necessary to use the program.

B. ORGANIZATION OF THE PAPER

Section II of this report describes the usual PERT analysis. A method for analyzing a PERT network and an example analysis are given. Section III explains the difference between the usual PERT analysis and a Monte Carlo analysis. Section IV discusses the intended uses of the program and describes the graphic displays and the hard copy output.

Section V contains operating instructions for the use of PERT-O-GRAPH. The use of the light pen, the programed function keys, and the alphanumeric keyboard associated with the 2250 Display unit are described.

Section VI is an example problem. It contains photographs of the graphic displays and illustrates how the user can change the PERT network.

Section VII is a description of the program. Concluding remarks appear in Section VIII, followed by the program listing.

II. PERT ANALYSIS

In the literature dealing with PERT networks the following terms are commonly used, and these definitions will be used throughout this discussion. The arcs of a PERT network are called activities and have associated with them some duration called te. The nodes of a network are called events, and they represent the completion of activities.

The PERT network is a description of the relationships among the activities. These activities must be finished before final project completion may be realized. There must be only one final event representing the job completion, and it must be possible to reach the final event from each node by following the arcs to successor nodes.

In the usual PERT analysis as described in ref. 2 and 3, there are three estimates required for each activity time. They are used to describe a beta distribution and are a most likely amount of time labeled m, and optimistic estimated on the time labeled a, and a pessimistic estimate labeled b. The mean time of completion (te) is computed by the formula:

$$te = \frac{a+4m+b}{6} .$$

The variance of the completion time associated with this mean is:

$$v = \left(\frac{b-a}{6} \right)^2 .$$

A mean and a variance is associated with each activity in the network. Then the network is analyzed for the earliest expected project completion time and the variance associated with this estimate.

A procedure and a computer program for solving a PERT network are given in ref. 2. The program was used as a model for PER-O-GRAPH

described below. The procedure is explained using the network in Figure 1.

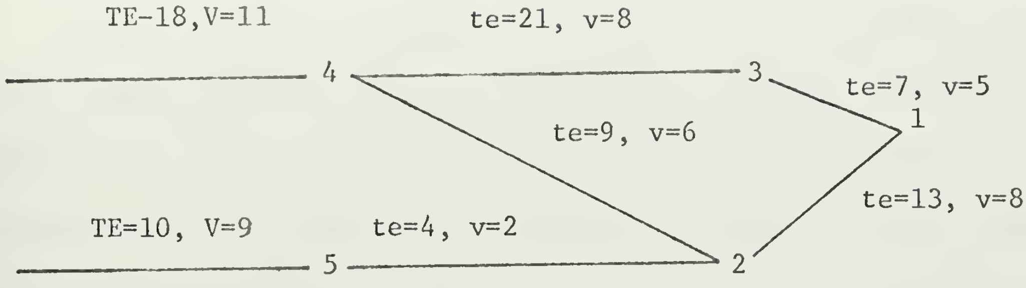


FIGURE 1. Example PERT Network

The earliest expect time of occurrence, TE, and the associated variance, V, for each event in the network is computed by traversing the network from beginning events towards the final event. The activity preceding event 5 starts at time zero so the expected time of completion of event 5 is time 10 and the variance is 9. The activity connecting event 2-5 cannot begin until after the completion of event 5 or at time 10. The earliest event 2 could occur on the basis of event 5 and its succeeding activity is 14 (10+4). However, before the TE for event 2 can be determined the effect of other activities leading to event 2 must be considered. The earliest activity 2-4 could be expected to be completed is 27 (18+9). Therefore, activity 2-4 governs the TE of event 2, and the TE of event 2 is 27. The variance for event 2 is determined by adding the variance of its governing immediate predecessor event and the variance of the activity connecting that event to event 2. Therefore the variance associated with event 2 is 17 (11+6). This process is continued until the TE and V for each event is determined.

For the above example the TE for event 1, the final event, is 46. Therefore the earliest expected time of completion of the job is 46 with a variance of 24.

The next step in solving the PERT network is to determine the latest expected time at which an event can be allowed to occur without delaying the completion of the project. This value is labeled TL and is determined by traversing the network from right to left as follows. Event 2 can be allowed to occur as late as time 33 (46-13) and event 3 can be allowed to occur as late as time 39 (46-7). Event 4 has two immediate successor events. The TL for event 4 is the smaller of the TL's determined by basing TL for event 4 on each of its immediate successor events. Basing it first on event 2, the TL for event 4 is 21 (33-9). Next basing it on event 3 the TL is 18 (39-21). Since this is the smaller of the quantities, the TL for event 4 is 18. The remainder of the network is then solved in this manner until the TL for each event is determined.

Next the "Slack" of each event is determined. This is the difference between the latest time at which the event can be allowed to occur without delaying the overall project completion time and the earliest time at which it can possibly occur. In formula form it is TL-TE. Events with a "Slack" equal to zero are critical events, and the path which joins the critical events is called the critical path.

Figure 2 is the solution of the PERT network in Figure 1. The critical path is the path along the arcs connecting events 4, 3, and 1.

The project completion times in the usual PERT analysis are assumed to approximate a normal distribution. In this example the project

completion times are assumed to be normal with mean 46 and standard deviation of 4.9.

	Event Numbers				
	5	4	3	2	1
TE	10	18	37	27	46
V	9	11	19	17	24
TL	23	18	39	33	46
SLACK	13	0	0	6	0

FIGURE 2. Solution for Example PERT Network

III. MONTE CARLO PERT ANALYSIS

The use of Monte Carlo techniques offers many advantages over the usual PERT analysis described in the previous section.

For a Monte Carlo analysis the network is drawn in the usual manner. However, instead of describing the distribution of each activity with the standard three parameters of m,a, and b, which assume a beta distribution, any distribution can be associated with an activity's duration time. This allows for greater flexibility and improved accuracy depending on how closely the distributions can be estimated.

A Monte Carlo analysis consists of a large number of simulations of the performance of the project. Each simulation has a possibility of estimating the time the actual project will take and the activities which will be critical. A simulation begins with the drawing of a random te from the distribution associated with each activity. The network is then solved in the usual manner except the variance is not computed. The project completion time and the identity of each arc which was on the critical path are saved. When the desired number of simulations is completed, the overall project completion time distribution can be determined by plotting the individual completion times or by performing a mathematical analysis of the stored completion times. The mean and standard deviation of this distribution give a more accurate prediction of the project completion time than the usual PERT analysis since the distribution need not be normal as is assumed in the usual method.

Rather than a prediction of a critical path, the criticality index for each activity is given. This is simply the percentage of the

analyses for which each activity was on the critical path. This gives an indication of how much attention on activity should be given by management to ensure the earliest possible project completion. This can be very valuable, especially if the completion times on two or more paths are close.

IV. USES FOR MONTE CARLO PROGRAM

The Monte Carlo PERT analysis program, PERT-O-GRAPH, is intended to demonstrate the way the critical path changes during a Monte Carlo analysis and to be an aid to a person learning this method to estimate project completion times. It can be used to solve small management problems, but due to the small buffer (4K) on the 2250 Display Unit at the Naval Postgraduate School for which this program was written, the arrays are limited so no more than fifty events and two hundred activities can be used. This number of events and activities could not be displayed simultaneously due to the buffer. Since most problems are larger than this, real life applications of the program are restricted.

The displays are designed to demonstrate the effect of changing activity duration distributions upon the criticality indexes and the distribution of project completion times, and the effects of adding and deleting activities on the project completion times.

PERT-O-GRAPH contains three main displays which are drawn on the 2250 screen. The main display is that of the PERT network. The nodes and arcs are displayed wherever indicated by the user. At the bottom of this display are strings of text called light pen functions which enable the user to communicate with the program and indicate what function he wishes to perform next. If the user indicates he wishes a mean time analysis to be performed, the mean time for each activity is displayed on the arcs and the mean time critical path is indicated by a double line along the critical arcs. When performing a Monte Carlo analysis the user may indicate that he wishes the analysis to be performed in such a manner that after each single analysis the duration

time for each activity is displayed on its arc, and, when called, the critical path for that single analysis will be displayed. This procedure gives an instructor the option of having his students calculate the critical path by hand and then have the critical path displayed to check the answer. It also demonstrates how the critical path can vary depending upon the length of time required to complete the various activities. After running a complete analysis the indicated number of times this display has the criticality indexes drawn on each arc in the network. This emphasizes the point that there is not necessarily only one critical path and that all activities must be supervised to varying degrees in order to realize the shortest project completion time.

The second display is for entering the distribution of activity duration times. The user can indicate and enter either a cumulative or frequency distribution. Only discrete distributions can be entered with the choice of twenty values on both the X and Y axes. After entering the distribution and returning to the main display, the user may refer to any activity, and if a frequency distribution was entered, a plot of either the frequency of cumulative distribution associated with that activity will be displayed in the lower left of the main display. If a cumulative distribution was entered, only the cumulative distribution can be displayed.

The third display is a plot of the distribution of the project completion times. The user designates the minimum time to be plotted, the width of the plot increments, and the total number of increments. A plot of completion times takes up half of the display CRT. When more than one complete analysis is run, the display shows the plot of the most recent analysis and that of the previous analysis. This allows a

quick comparison of how altering the network changes the project completion times.

In addition to the displays on the CRT there is a hard copy output for each completed analysis. This copy gives the sequential number of the analysis, how many iterations were made for that run, the mean and standard deviation of the project completion times, the upper limit of each increment, the per cent of total for each increment, and the cumulative percentage for each increment going from lowest to highest completion time recorded.

V. OPERATING INSTRUCTIONS FOR PERT-O-GRAPH

The operating instructions cover all the capabilities of PERT-O-GRAPH in such a manner that the user need have no former experience with the IBM 2250 display unit and he need not have any computer programming ability. The use of the light pen, the 2250 keyboard, the programed function keys and the displays are explained.

A PERT network entered into PERT-O-GRAPH has certain restrictions which must be met for successful execution. Node 1 must be the final event and it must be entered first. The rest of the noodes may be placed anywhere in the network, however, the internal execution of the program will be more efficient if the nodes are arranged such that the lower numbered events are in the direction of the final event. This arrangement is only an efficiency consideration and is not necessary for successful execution. A beginning event can have only one predecessor activity and the final event cannot have any successors. All the events in the network cannot have more than four immediate predecessor events or four immediate successor events. However, a problem in which an event has more than four immediate predecessors or immediate successors can be solved by using "dummy" events. The use of dummy events is illustrated in Figure 3. A maximum of fifty events can be entered and after event 50 appears no more events can be displayed. The maximum number of different distributions that may be defined is fifty.

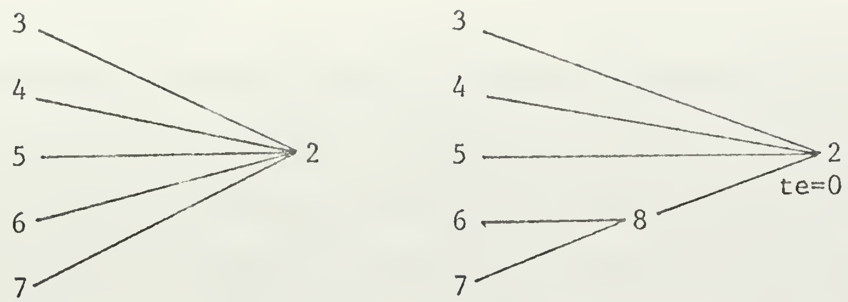


FIGURE 3. Use of "dummy" Events

A. LIGHT PEN FUNCTIONS

Most of the user controlled operations are communicated to the computer by means of the light pen. The light pen operations which the user can call are displayed in Figure 4 on page 39 as they appear at the bottom of the main display. In order to call a light pen function the light pen must be placed over the desired text and then the light pen foot switch depressed.

1. Enter Node

Nodes are numbered sequentially from 1. The first node entered will be 1, the second 2 etc.

After using the light pen to detect the "Enter Node" function the user will be instructed to "Position light pen before pressing function key." The light pen should then be positioned over the place on the 2250 display screen where the user desires the next node to appear. Next the programed function key four labeled "Locate L.P." should be pressed, and then the light pen foot switch depressed. When function key four is pressed the display will no longer be visible and the screen will be filled with W's. After depressing the light pen foot switch the PERT network will again be visible with the new node in the indicated position. All the nodes do not have to be entered before performing other functions.

2. Delete Last Node

The "Delete last node" light pen function causes the node just previously entered to be erased. If any function such as entering an arc has been performed since the last node was entered this option cannot be used, and the "Delete node" function must be used to erase a node. If the "Delete last node" function is used the node deleted can be used again. This is not true if the "Delete node" function is used. The "Delete node" function is explained below.

3. Enter Arc

After indicating the desire to enter an arc, the user is instructed to "Indicate node, then predecessor." By means of the light pen the user should indicate first the node, then the predecessor node between which the arc is to be drawn. After the arc appears the user has the option to delete the arc, "Delete last arc", enter a new distribution for the new arc's activity time, "Enter distribution", and "Read Dist from Card", or associate a distribution which has already been entered with the new arc, "Same distribution as arc."

If the "Delete last arc" option is selected with the light pen, the arc will disappear and the original list of options will appear.

After selecting the "Same distribution as arc" option, the user indicates with the light pen which arc has the already defined distribution and the new arc will share that distribution.

The "Enter distribution" option causes the screen to be erased and the two options "Cumulative distribution" and "Frequency distribution" to appear at the top center of the display surface. The method for entering distributions is explained in B below.

4. Enter Beginning Arc

The "Enter beginning arc" option must be used to enter the arc representing an activity with no predecessor event. After indicating this option the user is instructed to "Indicate beginning event." Then the three choices for entering distributions described under the Enter arc discussion are made available.

5. Delete Node

The "Delete node" light pen function allows the user to delete a node anywhere in the PERT network. After selecting this function the node to be deleted should then be indicated with the light pen, and it will be erased. The number on this node will not be reused and the next node entered will be sequenced as if no node were deleted. Since the final event must always be node 1, this option should not be used to delete node 1. After a node has been deleted any arcs leading to or from the deleted node must be deleted by using the "Delete arc" function.

6. Delete Arc

If the user wishes to delete an arc for which a distribution of completion times has been entered, the "Delete arc" function must be used. After choosing this function, the light pen is used to indicate the arc to be deleted, and that arc is erased from the network.

7. Restart

"Restart" reinitializes the display. The PERT network displayed is completely erased as are all distributions of completion times previously entered. The first node entered after a restart has the number 1. This function is usually used before a completely new network is entered for analysis.

8. Change Only Dist of Arc

The "Change only dist of arc" function allows the user to change the distribution of an arc which is using a shared distribution without changing the shared distribution or to change the distribution of an arc which is not using a shared distribution. After selecting this function the user should indicate which arc is to have its distribution changed. Then the options to assign a new distribution or to share a distribution are presented.

9. Change Common Dist of Arc

The "Change common dist of arc" function is used to change a distribution which is associated with more than one arc. After selecting this function, one of the arcs using the common, or shared distribution should be indicated with the light pen. Then a new shared distribution may be entered, or a previously defined distribution can be associated with the arcs sharing the distribution by indicating which arc is associated with the desired distribution. This function may also be used to change the distribution of an arc which is not sharing a distribution with other arcs, but the "Change only dist of arc" function is more efficient for this purpose.

10. Display Freq Dist of Arc

The "Display freq. dist of arc" function is used to display a frequency distribution associated with an arc. It can only be used if the distribution was entered as a frequency distribution. After choosing this function, the user indicates the arc whose distribution is to be displayed, and the frequency distribution will appear in the lower left corner of the 2250 display. Pressing programed function key 3

labeled "Go on" erases the display of the distribution and allows further function calls.

11. Display Cum Dist of Arc

The "Display Cum dist of arc" function is used to display the cumulative distribution associated with an arc. It does not matter whether the distribution was entered as a frequency or a cumulative distribution. After choosing this function, the arc whose distribution is to be displayed should be indicated and the cumulative distribution will appear in the lower left corner of the 2250 display. To erase the display of the distribution and allow further function calls the programed function key 3 labeled "Go on" must be pressed.

12. Quit

The "Quit" light pen function ends the program and disables the 2250 display unit.

13. Execute

The "Execute" light pen function indicates that the PERT network is complete and ready to be analysed. After selecting this light pen function the user has no means of changing the network until the analysis is completed.

B. PROGRAMMED FUNCTION KEYS

The IBM 2250 Display Unit has associated with it a programed function keyboard. There are 32 keys numbered from 0 to 31. In PERT-O-GRAPH, keys 0 through 6 are used. The lights inside these seven keys are on only when they may be used, however the user must be careful to press the correct key depending on what part of the program is currently being executed. Pressing a key causes an interrupt and a message to be

communicated to the program, and pressing the wrong key may cause unpredictable results.

1. <u>End Dist (P.F. Key 0)</u>

This P.F. key is used when entering a distribution of activity completion times. It indicates that the distribution has been completely entered. Before pressing this key the user should check that the distribution is correct, since after it is depressed the distribution is entered into the program and one of the functions to change the distribution of an arc would have to be called to correct the distribution.

2. <u>End of Char (P.F. Key 1)</u>

This P.F. key is used after entering characters by the alphanumeric keyboard. Pressing this key will remove the cursor from the character string and enter the character string into the program.

3. <u>Restart Plot (P.F. Key 2)</u>

This P.F. key can be used when entering the plot of a distribution of activity completion times. It causes the labels on the X axis and the plot to be erased. It will be recognized only after the first point is plotted.

4. <u>Go On (P.F. Key 3)</u>

This P.F. key communicates to PERT-O-GRAPH that the user wishes the program to execute the next step in the program. The result depends upon the step presently in progress.

a. Singl Step Executi n

When pe forming a Mo te Carlo analysis in single step mode, the te for each arc is displayed when the single analysis is completed.

Pressing this key after the te's are displayed will cause the critical path to be drawn.

b. Criticality Indexes Displayed

Pressing P.F. key 3 when the criticality indexes are displayed after a complete Monte Carlo analysis will cause the PERT network to disappear and the plot of the project completion times to be drawn.

c. Distribution of Project Completion Times Displayed

Pressing P.F. key 3 when the distribution of project completion times is displayed will cause the distribution to be erased from the screen, the PERT network to appear, and will allow alteration of the network.

d. Mean Time Calculation

After a mean time calculation, the te's and critical path are displayed. Pressing P.F. key 3 at this time will cause the te's and critical path to be erased and allow the user to enter the number of analyses to be performed in the Monte Carlo analysis.

5. Locate L.P. (P.F. Key 4)

After indicating that a new node is to be entered, pressing P.F. key 4 will cause the 2250 display area to be filled with W's. This is necessary for the light pen to detect the coordinates where the new node is to be drawn.

6. Step (P.F. Key 5)

This key is used when performing a Monte Carlo analysis in the single execution mode. After the critical path is displayed pressing this key will cause the next analysis to be performed.

7. Continue, No Reset (P.F. Key 6)

After a complete Monte Carlo analysis has been performed and the plot of project completion times is displayed, this key is used to indicate that the same network is to be solved an additional number of times.

C. ALPHANUMERIC KEYBOARD

The alphanumeric keyboard attached to the 2250 Display Unit allows the user to enter characters into the display. In order for a character to be entered into the display a cursor must be in the display. The cursor is inserted automatically by PERT-O-GRAPH when information is to be entered via this keyboard. After a character is entered, the cursor moves to the next position where a character can be entered.

The ADVANCE key moves the cursor one position without changing the character above the cursor. Pressing P.F. key 1 will remove the cursor and enter the text into PERT-O-GRAPH. Hitting the ALT and CANCEL keys simultaneously will cause the display to disappear and the text "*TERMINATE", "*DUMP", and "*RESUME" to appear. Detecting on "*TERMINATE" and "*DUMP" with the light pen will cause the program to terminate, and "*RESUME" will return the display and execution will continue.

D. DRAWING A DISTRIBUTION

After entering an arc or indicating the desire to change the distribution of an arc and then indicating a new distribution is to be entered by the user the 2250 screen will be erased and the text "Cumulative distribution" and "Frequency distribution" will appear at the top center of the display. The light pen is used to indicate the type of distribution to be entered. This will cause an X and Y axis to appear.

Each axis is divided into twenty segments by strokes along the axis. The Y axis is labeled from 0.0 to 1.0.

1. <u>Labeling the X Axis</u>

The extremes on the X axis are entered by the user. A cursor first appears to the left of the axis where the left extreme is entered. The extremes are entered by using the 2250 display unit keyboard. After entering the left extreme, pressing programed function key 1 labeled "End of char." will cause the cursor to appear to the right of the X axis. The right extreme is entered in the same manner. The axis will be labeled along its length with increments of one-tenth of the difference between the extremes. It is not necessary to enter the most optimistic and most pessimistic times as the extremes. The extremes should be chosen so the axis will be labeled with points that are to be used in the plot. As an example, if the user wished to plot points between 7 and 13 he might enter the extremes of 5 and 15. This would cause 5.0, 5.5, 6.0, 6.5, etc. to be entered along the axis. If 7 and 13 were entered as the extremes, the labels would be 7.0, 7.6, 8.2, 9.4, etc. The maximum value that can be entered as either extreme on the X axis is 9999.9. All values entered must contain a decimal point and may contain one digit to the right of the point.

2. <u>Drawing a Cumulative Distribution</u>

To enter the starting point of a distribution the light pen is used to indicate the vertical hash mark on the X axis representing the most optimistic estimate. The distribution is drawn by first indicating the X value of the point by detecting one of the hash marks on the X axis and then indicating the Y value by detecting one of the hash marks on the Y axis. PERT-O-GRAPH will draw lines between succeeding points.

Any discrete cumulative distribution of twenty points or less can be drawn. The last point entered must have a Y value of 1.0. When finished entering the distribution, programed function key 0 labeled "End dist" should be pressed. The distribution will then be entered, and the display of the PERT network will reappear.

3. Drawing a Frequency Distribution

To enter the starting point of a distribution the light pen is used to indicate the vertical hash mark on the X axis representing the most optimistic estimate. To draw the distribution first indicate the X value of the point by detecting one of the hash marks on the X axis and then indicate the position of the Y value by detecting one of the hash marks on the Y axis. The values on the Y axis can be thought of as positions instead of values since PERT-O-GRAPH will draw lines between succeeding points and internally adjust the values so the area under the finished plot is equal to 1.0. When finished entering the distribution, programed function key 0 labeled "End dist" should be pressed. The distribution will then be entered, and the display of the PERT network will reappear.

4. Error Correction

If an error is made when entering a distribution, the plot and the X axis labels can be erased by pressing programed function key 2 labeled "Restart plot". This key can be used any time after the first point is entered.

E. ENTERING A DISTRIBUTION FROM PUNCHED CARDS

A distribution may also be entered from punched cards by detecting the "Enter dist from card" light pen function. If distributions are to

be entered using this option, the punched cards must be entered at the end of the program deck prior to submitting the program for execution. Only cumulative distributions can be entered through this function.

The first card for each distribution must contain the number of points used to describe the distribution. This number must be an integer and it must be placed in the first six columns of a card. The last digit must be in column six as any trailing blanks will be interpreted as zeroes.

The points in the distribution are entered on separate cards. The first number on a card is read as the X value. It must be entered in the first six columns of a card. If no decimal point is entered the default format of F6.1 will be assumed. The second number on a card is read as the Y value of the point and it must be entered in card columns seven through twelve. If no decimal point is entered, the default format of F 6.3 will be assumed.

The user should be careful to place the distributions in the order in which they are to be entered as they cannot be read out of order.

Once a distribution is read from cards it cannot be read again.

F. EXECUTION

After indicating that an execution is desired the original list of options is erased from the screen and the two options "Mean time calculation", and "Execute-Analyses" appear. The mean time calculation will perform only one analysis and display the mean time of project completion using the mean time for each activity. This is similar to the usual PERT analysis. By indicating the number of analyses to be made the user indicates that a Monte Carlo analysis is to be made.

1. Mean Time Calculation

When a mean time calculation is selected with the light pen the mean time is written to the right of "Mean time calculation" and the mean time of each activity's completion time is displayed on its arc. Also the mean time critical path is indicated by a double line along the arcs on the critical path in the PERT network. The user may now indicate the number of analyses to be performed in the Monte Carlo analysis.

2. Monte Carlo Analysis

To begin a Monte Carlo analysis enter the number of analyses to be run in "Execute - Analyses" with the 2250 keyboard. The largest number that can be entered is 9999. If less than 1000 analyses are desired, this number must end with a decimal point. After this number is entered, function key 1 should be pressed, and then the user will be directed to enter "Minimum time." This is the minimum time that will be plotted in the distribution of project completion times. The largest number that can be entered here is 999999.9 and a decimal point must be included. Next the user is directed to enter the "Width of increments." This is the distance between points in the plot of project completion times. This number also can be no larger than 999999.9 and must contain a decimal point. After again pressing function key 1, the user is directed to enter "No. of increments." This is the number of points to be plotted in the distribution of project completion times. The maximum number of points is 50, and the number must end with a decimal point.

After entering this information the user must make the choice of "Single execution" or "Complete analysis."

3. Single Execution

If the "Single execution" mode is chosen with the light pen, one analysis will be performed, and the te picked for each activity will be written on that activity's arc. Next, programmed function key 3 should be pressed, and the critical path will be displayed by a double line along the arcs of the critical path. If another single execution is desired, it may be performed by pressing function key 5 labeled "Step" or by detecting "Single execution" with the light pen. After any single execution the user may go to the complete analysis mode by indicating "Complete analysis" with the light pen.

4. Complete Analysis

When the "Complete analysis" mode is selected, the number of Monte Carlo analyses indicated are performed, and when they are completed the criticality index for each arc is written along each arc. This indicates the percentage of the time an arc was on the critical path. After the criticality indexes are displayed, pressing programed function key 3 will cause the PERT network to be erased and a plot of the project completion times to be displayed. The current plot fills half of the screen and the previous plot fills the other half.

At this point, the user has two options. He can press function key 3 ("Go On") and the program will return to the point where modification of the PERT network is allowed. If function key 6 labeled "Continue, no reset" is pressed the user will be directed to enter the number of additional analyses to be performed and then to indicate step execution or complete execution. The "Continue, no reset" function does not reset any of the data already compiled and allows for additional executions to smooth the curve of project completion times.

G. SUBMITTING A RUN

PERT-O-GRAPH is complete by itself and can be run by a user with no additions except a JOB card unless he wishes to read distributions from cards. The green JOB card is placed at the beginning of the program deck and it must contain the phrase TYPERUN=HOLD. Cards containing distributions of activity duration times must be placed immediately before the orange /* card which is at the end of the program deck.

VI. SAMPLE PROBLEM

The problem described in this section is to determine the distributions of activity duration times necessary to cause the plot of project completion times for the network shown in Figure 4 on page 39 to have a mean below 50.0. The network represents the jobs in the project which must be completed and the order in which the jobs must be started. Node 1 was entered first, then the remaining nodes and arcs were entered.

Some of the distributions of activity duration times were entered from punched cards and some were entered by drawing the distributions on the display unit. The distribution for arc 5-8 was drawn, and is shown in Figure 5 on page 40 . Before the beginning arc entering node 7 was entered, the distribution for arc 8-5 was displayed as shown in Figure 6 on page 41 . Since this was the same as the distribution desired for the beginning arc entering node 7 this arc was designated to share the distribution of arc 5-8.

There were six distributions entered for the twelve arcs. The points in the distributions and the arcs which were associated with these distributions are given in Table 1 on page 50 .

After the complete network was entered, a mean time calculation was executed. This resulted in a mean time of 51.4 and a critical path along the arcs connecting nodes 8,6,3, and 1.

Next a Monte Carlo analysis of 1,000 executions was specified. Using the mean time calculation as a basis, a minimum time of 30.0, a width of increment of 1.5, and the number of increments 30 were entered for the plot of project completion times. When this analysis was

completed, the mean time of the plot of the project completion times was 54.9 with a standard deviation of 4.0. It was then run again for another 1000 executions.

The criticality indexes based on these 2000 executions are shown in Figure 7 on page 42 . The mean time of project completion times resulting from those 2000 analyses was 54.9 with a standard deviation of 4.1. Since these values were so close to the values obtained from 1000 analyses, additional executions to smooth the curve of completion times and to calculate the criticality indexes were felt unnecessary.

The estimated mean time of project completion using a Monte Carol analysis was 54.9 as compared to a mean time of 51.4 using a mean time calculation which is similar to the usual PERT analysis. This is the same type of results as were described by Van Slyke in ref. 3.

Next an attempt was made to lower the mean time of the project completion times. The arcs with the highest criticality indexes seemed to be the logical ones to alter. Arc 1 - 3 had a criticality index of .73 so this arc was changed first. A uniform distribution between the times of 5.0 and 12.0 was entered for this arc's distribution of duration times. 2000 analyses were specified and the same parameters for the plot of project completion times were entered. This is shown in Figure 8 on page 43.

This analysis was first run in the single step mode so the changing of the critical path could be observed. The resulting critical path from two individual analyses are shown in Figures 9 and 10 on pages 44 and 45.

The analysis was then run in the complete analysis mode to the finish. This resulted in a plot of project completion time with a mean

of 53.5 and a standard deviation of 4.2. The plots of the two complete analyses are shown in Figure 11 with the old plot at the top of the display and the new plot at the bottom.

Another attempt was then made to lower the mean of the distribution of the project completion times. The arc with the highest criticality index in the last analysis was arc 4 - 7 with an index of .65. The distribution of duration times for this arc was changed to a cumulative distribution uniform over the times from 7 to 15. The network was then analysed 2000 times with a resulting distribution of project completion times with a mean of 49.1 and a standard deviation of 4.0.

This problem illustrates how the user can experiment with a PERT network using PERT-O-GRAPH. He can see how the critical path changes with different activity durations, and he can observe the effect of altering the network on the distribution of project completion times.

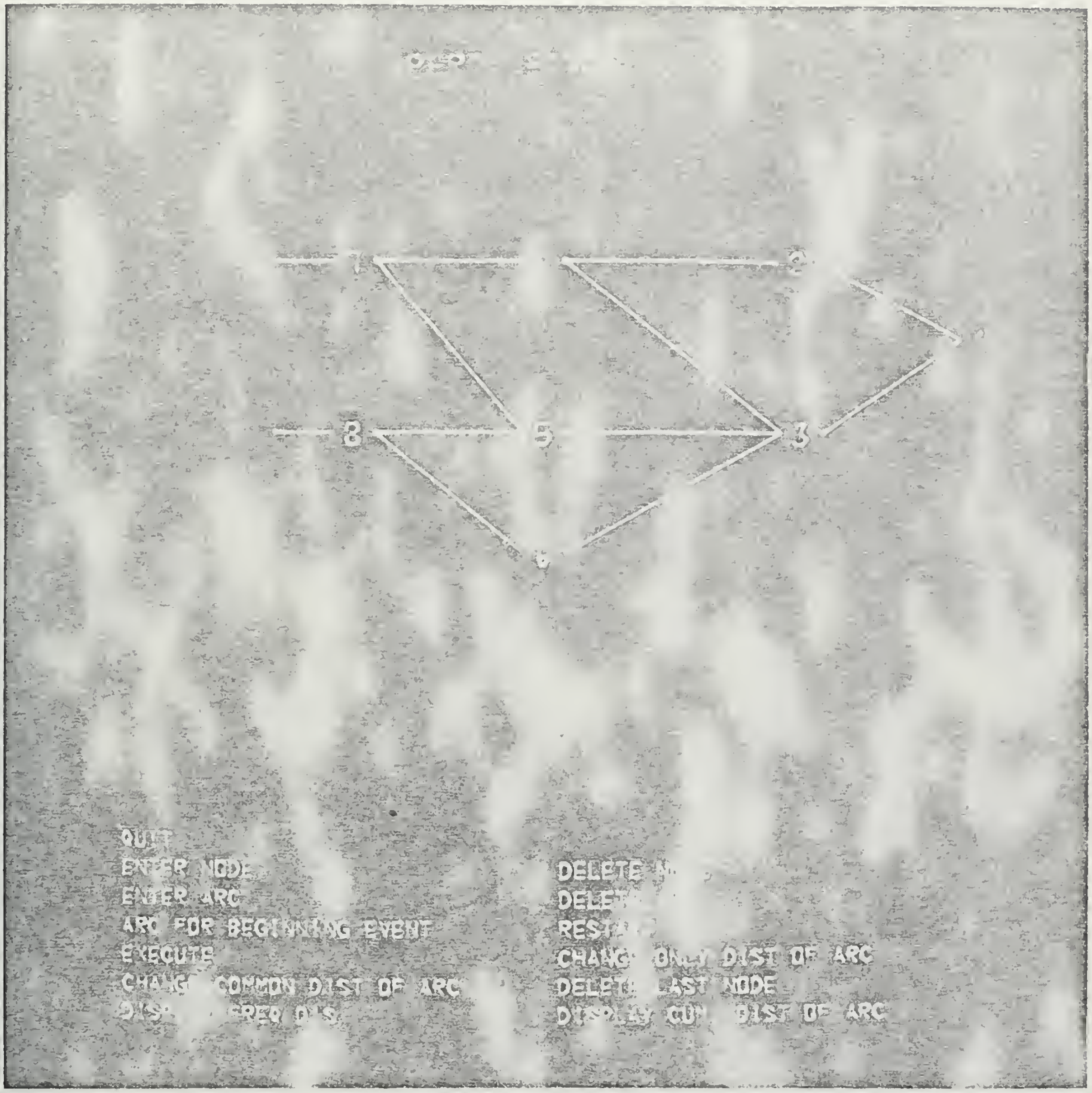


FIGURE 4. PERT Network Analyzed in Example Problem

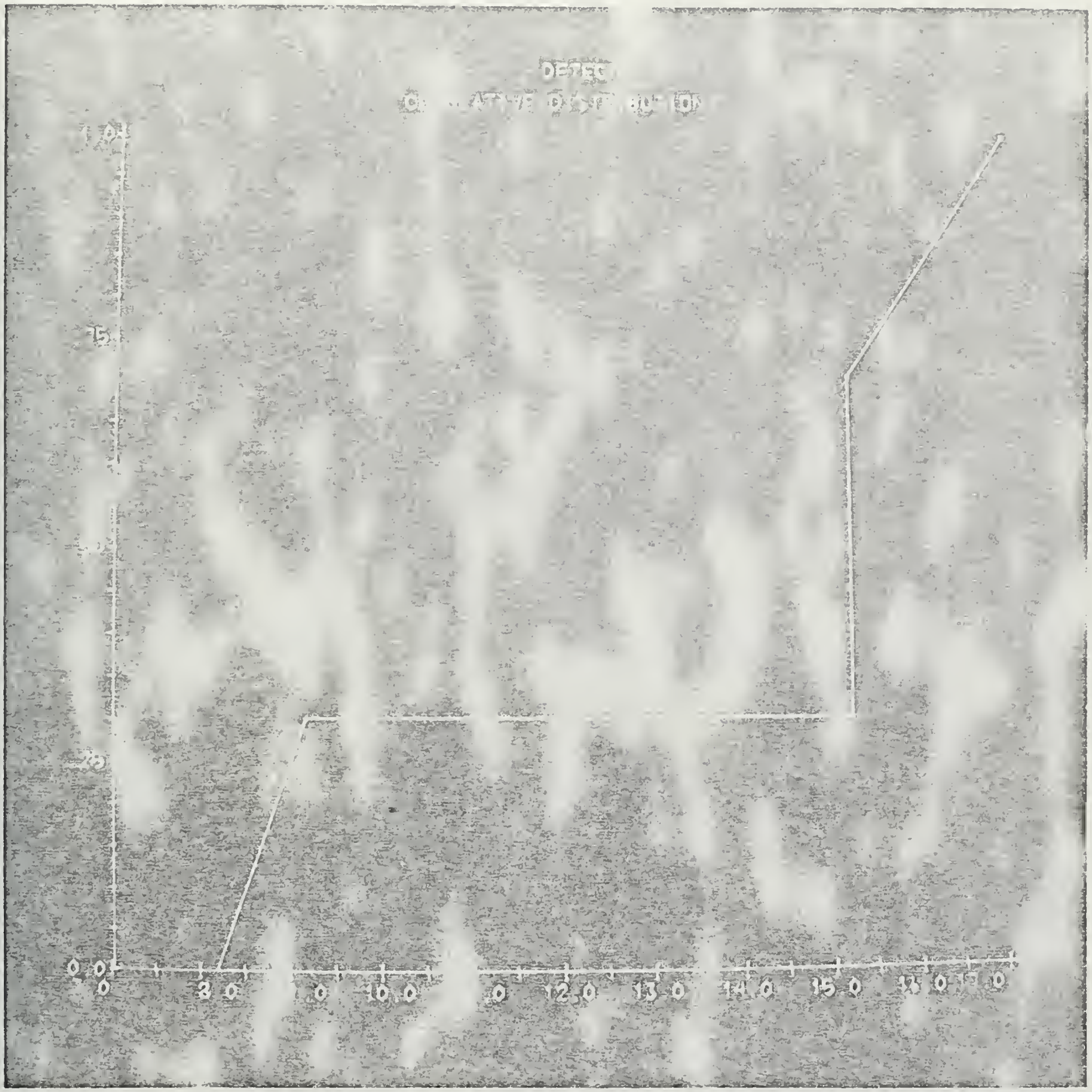


FIGURE 5. Cumulative Distribution drawn by light pen

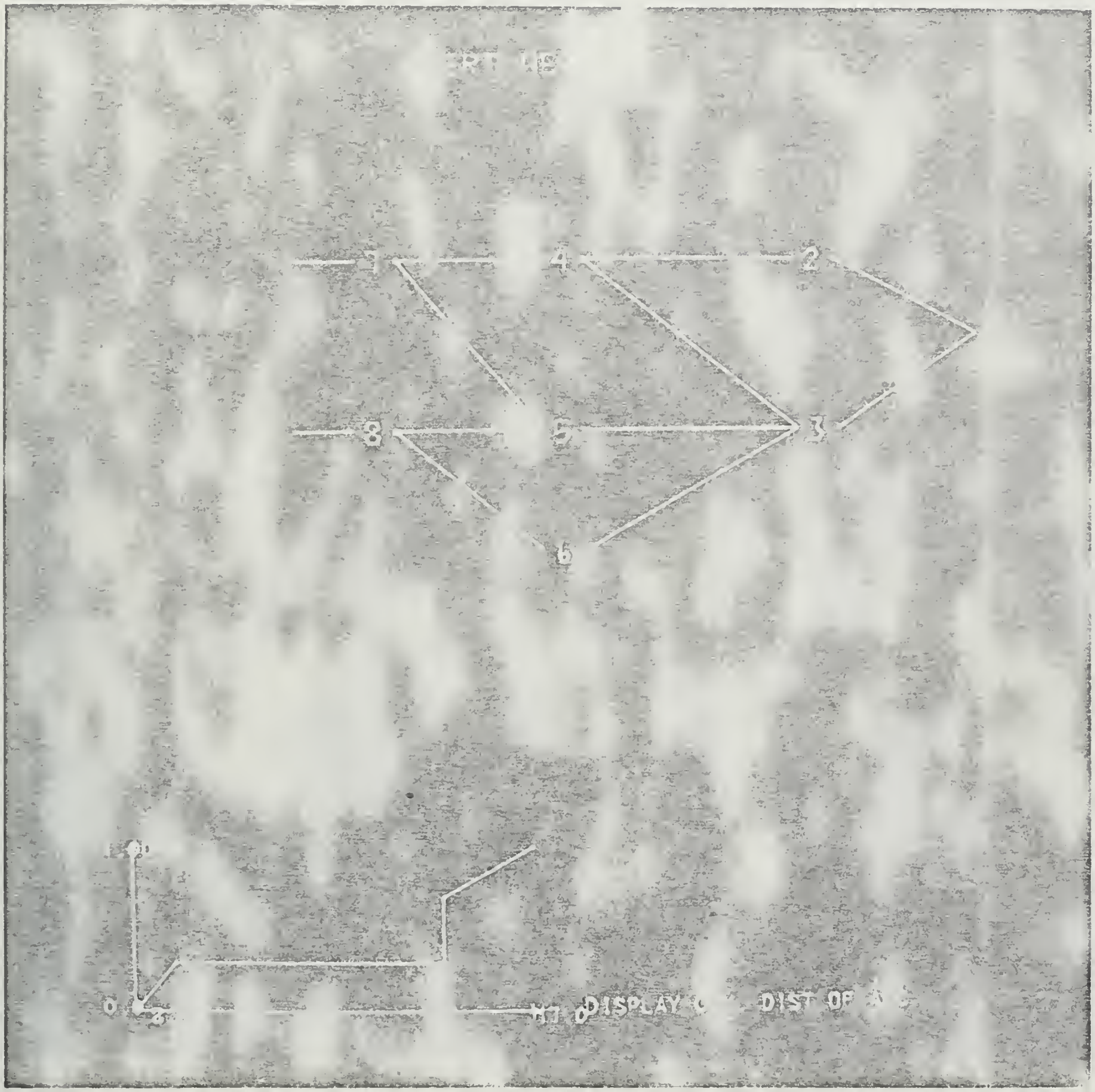


FIGURE 6. Display of Cumulative Distribution associated with an Arc.

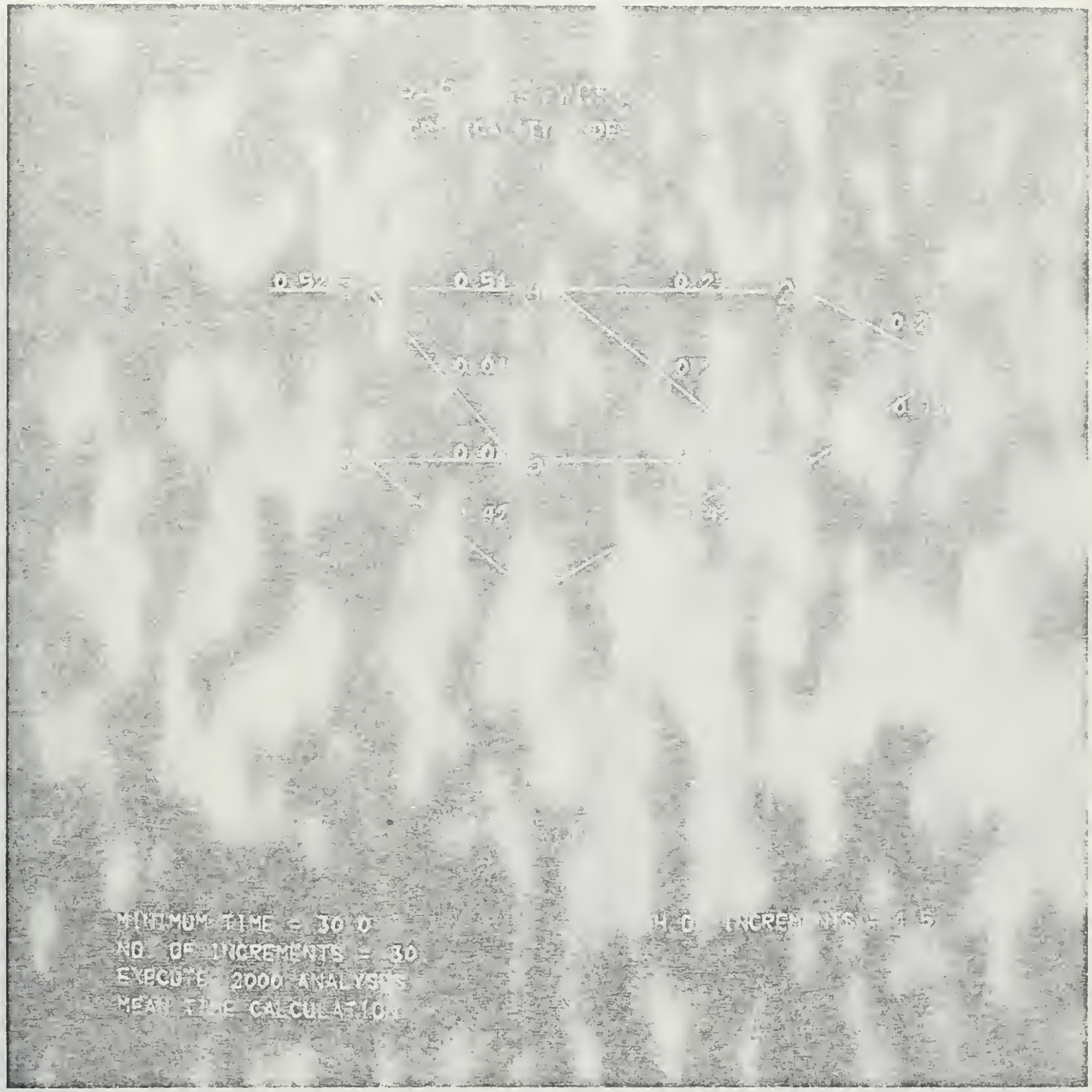


FIGURE 7. Display of Criticality Indexes

FIGURE 8. Display of Parameters for Plot of Distribution of Project Completion Times.

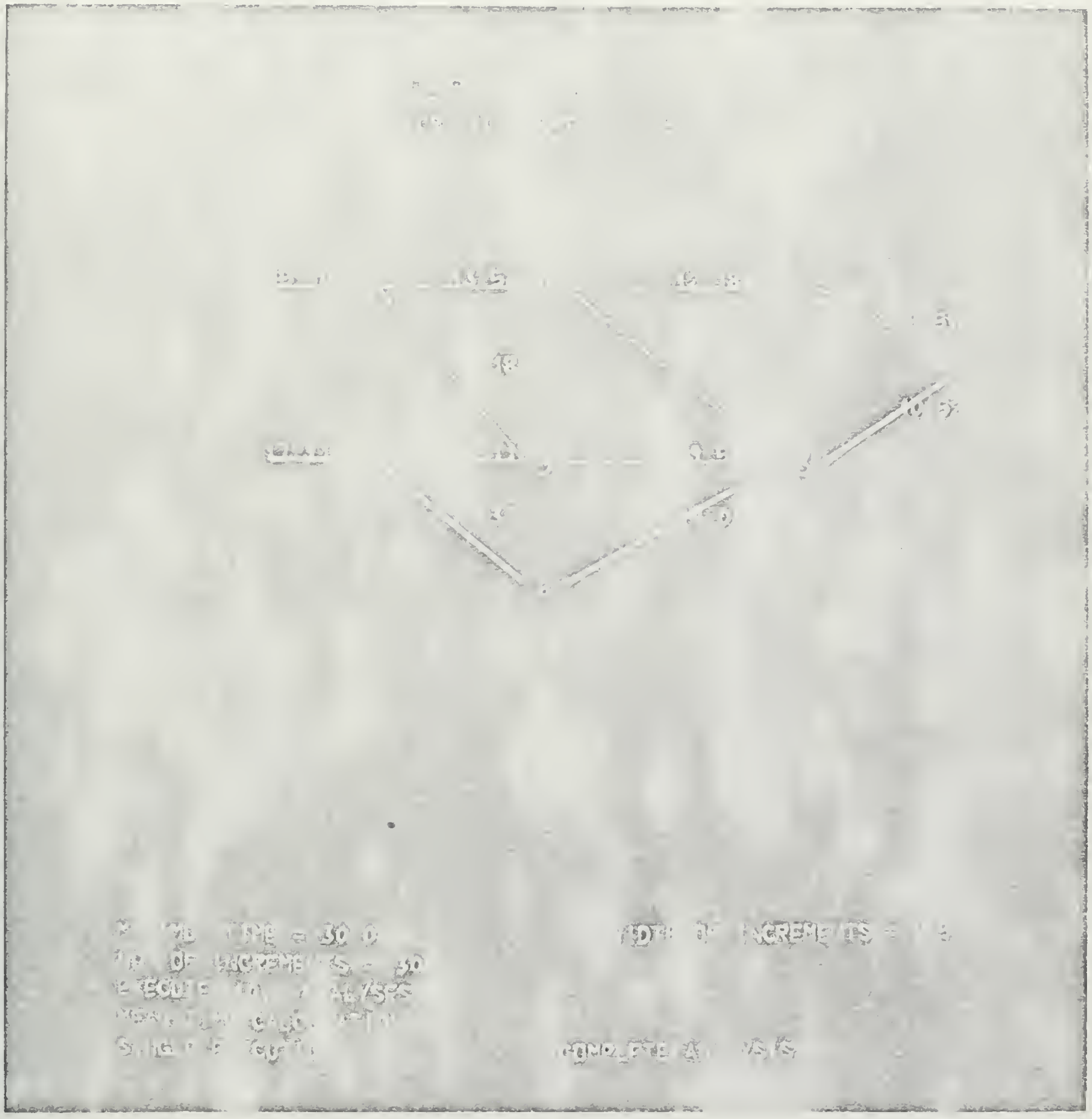


FIGURE 9. Display of Network with critical path shown

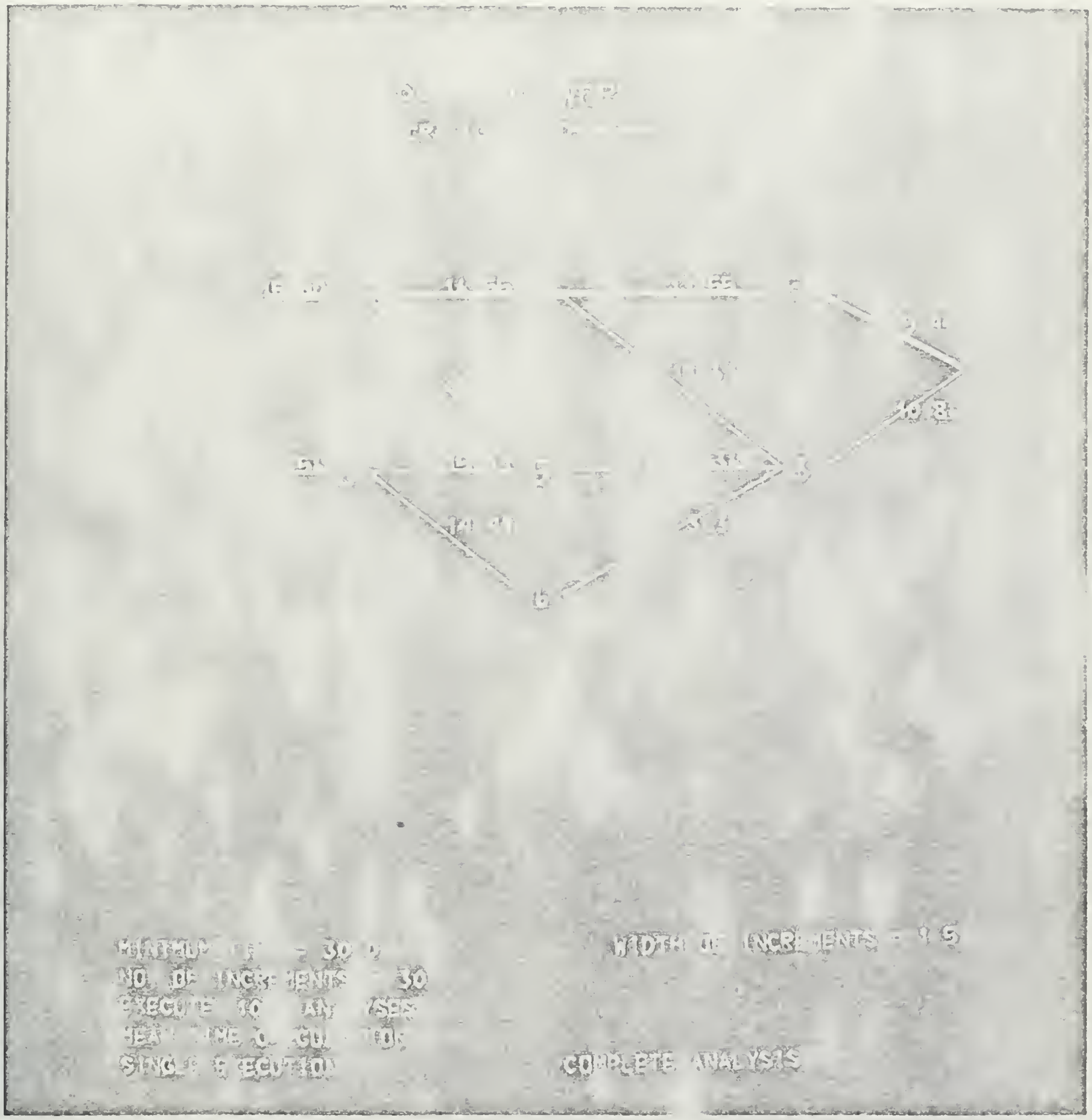


FIGURE 10. Display of Network with Critical Path changed

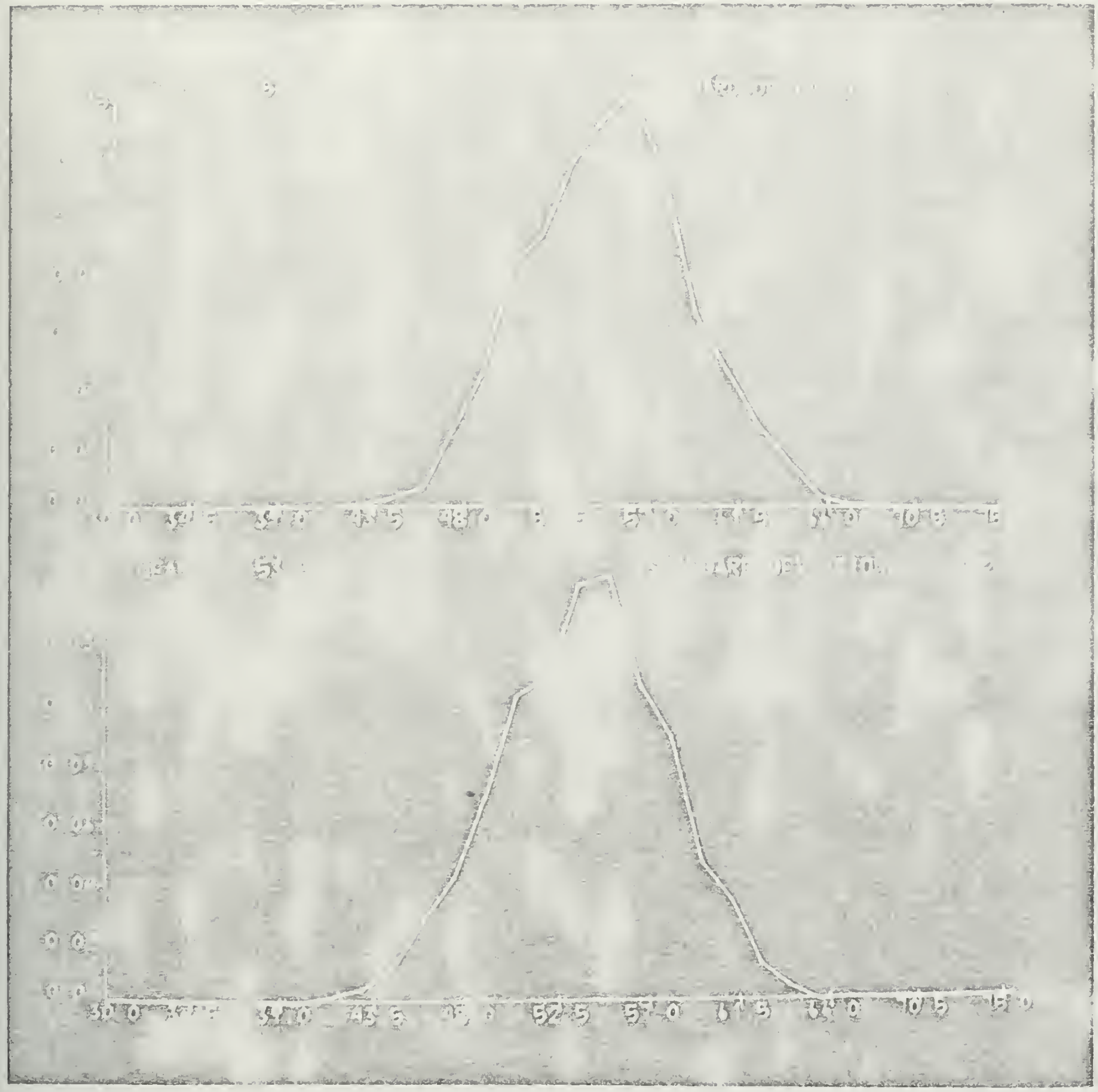


FIGURE 11. Display of Plots of Distributions of Project Completion times

VII. PROGRAM DESCRIPTION

PERT-O-GRAPH is written for an IBM 360/67 with an IBM Display Unit Model 1. The Display Unit is described in detail in ref. 4. The program is written in FORTRAN IV, described in ref. 5, to run on a machine with OS/360 release 18 and an IBM Graphics Subroutine Package described in ref. 6.

The program for the PERT analysis is modeled after a PERT program given in ref. 1. The model program has been expanded to handle nodes with four immediate successor and four immediate predecessor events.

A. MAIN PROGRAM

The main program controls the 2250 displays, the calling of subroutines, the filling of the various arrays, determining the critical path and completion time of the PERT network, and the printing of the hard copy output.

1. The 2250 Displays

The display for the PERT network is entered into its own graphic data set. This data set is equivalenced with two other data sets. One of these data sets is used when entering a distribution and one is used in the plot of project completion times. When one of these other data sets is called, the data set with the network is overlayed in the 2250 buffer and a copy is retained in the 360's core. When the data set containing the network is recalled, it overlays an equivalent data set in the buffer and reappears.

The nodes in the network have a correlation value assigned so they can be identified by light pen detections. The correlation value assigned is the same as the number of the node. The arcs in the

network are correlated with a number which identifies the two nodes between which the arc is drawn. For example, an arc correlation value of 0310 identifies the arc going from node 3 to predecessor node 10.

The text which appears on the screen for light pen functions and instructions to the user is placed in its own data set. This data set is completely erased when the program jumps to another section of code. The reason this text is not written just once and then placed in include or omit status when needed is that it was found that the text took up too much buffer space when used in this manner. By completely resetting the data set, the buffer space used by this data set is freed for other uses.

The display for entering a distribution is composed of two graphic data sets. One data set contains the axes, the labels on the axes, and the plot. The other contains only the hash marks on the X and Y axes. The light pen is enabled to detect only the data set which contains the hash marks. Only six characters can be entered for the left and right extremes. This allows a space equal to the size of one half character between strings of numbers after the entire X axis is labeled. When the user enters the X coordinate of a point, the program saves the absolute X coordinate for plotting the point. The time value associated with this point is computed by scaling. The coordinate and time value for the Y axis are handled similarly. The same display is used to enter a frequency or a cumulative distribution.

The plot of the distribution of project completion times involves the use of two data sets. After two complete analyses, both data sets contain a plot. After the third analysis, the oldest plot is erased and the new plot is entered in the cleared data set. In this

manner the current and last distribution are displayed simultaneously. The extremes on the X axis are determined by the values the user enters for "Minimum Time", "Width of Increment," and "Number of Increments." The smallest increment includes the number of completions which fall in that increment as well as those that are less than the minimum value. The largest valued increment includes the number of completions which fall in that increment as well as those that are greater than the right extreme. The Y axis is labeled from 0.0 to the maximum percentage of completions any increment contains. The plot is a series of straight lines. The X coordinates for the end of each line plotted are the centers of the increments except for the two extremes. The plot starts at the Y axis and ends with the right extreme. The value of the Y coordinate represents the percentage of completion times in each increment.

2. Arrays

There are three main arrays in the program. The EVT array, dimensioned 50 by 20, contains the data necessary for the PERT analysis. The IPT array, dimensioned 50 by 4, is linked to the EVT array and contains pointers to the array containing the distributions of activity duration times. The DIS array is dimensioned 50 by 20 by 3 and contains the distributions of activity duration times.

The first subscript of the EVT array indicates the number of the node. The data contained in the EVT array is explained in Table 1 on page 50.

The first subscript of the IPT array indicates the number of the node. The second subscript indicates the location of a pointer in the array for a particular arc's distribution of duration times.

EVT(N,1):	Number of event N's first I. P. (Immediate Predecessor)
EVT(N,2):	The te associated with N's first I. P.
EVT(N,3):	Number of event N's second I. P.
EVT(N,4):	The te associated with N's second I. P.
EVT(N,5):	Number of event N's third I. P.
EVT(N,6):	The te associated with N's third I. P.
EVT(N,7):	Number of event N's fourth I. P.
EVT(N,8):	The te associated with N's fourth I. P.
EVT(N,9):	TE of event N
EVT(N,10):	Number of event N's first I. S. (Immediate Successor)
EVT(N,11):	The te associated with N's first I. S.
EVT(N,12):	Number of event N's second I. S.
EVT(N,13):	The te associated with N's second I. S.
EVT(N,14):	Number of event N's third I. S.
EVT(N,15):	The te associated with N's third I. S.
EVT(N,16):	Number of event N's fourth I. S.
EVT(N,17):	The te associated with N's fourth I. S.
EVT(N,18):	TL of event N
EVT(N,19):	SLACK of event N
EVT(N,20):	0 if event current, 1 if event deleted

TABLE 1. Definition of EVT Array

For example IPT(N,1) contains a pointer to the distribution of duration times for event N's first immediate predecessor, IPT(N,2) points to the distribution for N's second immediate predecessor, etc.

The DIS array contains the distributions of activity duration times. All the distributions are stored as cumulative distributions even if they are entered as frequency distributions. The first subscript is the number of the distribution and is pointed to by the IPT array. The second subscript is the number of the point in the distribution. A distribution must be described with twenty points or fewer. DIS (I,J,1) contains the cumulative distribution's Y value for the Jth point of the Ith distribution; DIS (I,J,2) contains the corresponding X value; and DIS (I,J,3) contains the corresponding Y value for the frequency distribution if the user enters the distribution as a frequency distribution. If the user enters a cumulative distribution, the cells for the Y value for the frequency distribution are set to zero.

When an arc is entered, the identity of the predecessor is entered into the EVT array. Then the pointer to the distribution of activity duration times is entered into the IPT array.

The ITCRT and ICRIT arrays are dimensioned 50 by 4. The ITCRT array keeps the information on which arcs are on the critical path when doing a mean time calculation or a Monte Carlo analysis in the single step mode. The ICRIT array keeps a count on how many times each arc was on the critical path for the criticality index calculation. The IHIS array is a vector of length 50 which contains the total number of completions which fall into each increment. The LOC array is dimensioned 50 by 2 and contains the X and Y coordinates of each node. The PLOT

array is a 50 by 2 array of points to be plotted by the DISPLY subroutine. The P array is a vector of length 150 used as a stack of pointers in the analysis of the PERT network.

3. Analyzing the PERT Network

If the user desires a "Mean Time Calculation" to be performed, he must indicate this before entering the number of iterations to be performed in a Monte Carlo analysis.

Before determining the mean time critical path and completion time, the mean duration of each arc is calculated. This is determined by calling subroutine MEAN for each arc and then entering the mean time for each arc's distribution into the EVT array as that arc's te. The analysis is then run once and the mean time for each arc's duration, the mean time for completion, and the mean time critical path are displayed. The user may then chooose a Monte Carlo analysis.

In a Monte Carlo analysis, before determining the critical path and completion time of a network, a te is determined for each arc. This is accomplished by generating a random number between 0.0 and 1.0 in the RAND subroutine, entering the SETTE subroutine with this number, and calculating a te from the associated distribution for an arc. The te is then entered in the appropriate place in the EVT array. This procedure is repeated for each arc in the network. After all the te's are entered, the TE for each node is computed. The program then calculates the TL for each node. Next the "SLACK" for each node is calculated by subtracting the TE from the TL for each node.

The program next determines which arcs are on the critical path. This is done by first checking each node's slack. If the slack is zero, it checks each arc that entered the node, and if the TL of the

node minus the te associated with the arc equals the TL of the predecessor, and the predecessor also has a slack of zero, then that arc is on the critical path. The critical arcs are tabulated in the ICRIT array for a complete analysis and in the ITCRT array for display of the single step critical path. This process is repeated the number of times specified by the user.

B. SUBROUTINES

The function of each of the subroutines in PERT-O-GRAPH and descriptions of their execution are included in this section.

1. Subroutine DIST

This subroutine enters a distribution of an activity's duration times into the DIS array. If a cumulative distribution is drawn on the 2250, it is entered into the array exactly as plotted. If a frequency distribution is drawn, the main program changes it into a cumulative distribution. The user is cautioned that the cumulative distribution resulting from this conversion is represented internally as a series of straight lines, the same number of straight lines as was used to draw the frequency distribution. If a greater number of lines is used to draw the frequency distribution, the resulting cumulative error will be reduced. For example, a triangular distribution drawn with two lines becomes a straight line cumulative distribution. However, if many short line segments are used to draw the same frequency distribution, the resulting cumulative will more nearly resemble the correct curved line cumulative distribution. Figure 12 illustrates this result.

An unavoidable error is caused by the 2250 light pen detections. The 2250 rounds the raster unit coordinates of a detection so that when the coordinates are converted to values on the X and Y axes, slight errors may result.

2. Subroutine MEAN

This subroutine calculates the mean of the distribution of an activity's duration times. The mean is determined by calculating the average X value under each line segment of the cumulative distribution, weighing these values according to the amount of the Y axis spanned by each line segment and taking the sum of these weighted values. This sum is returned as the mean of the distribution.

3. Subroutine RAND

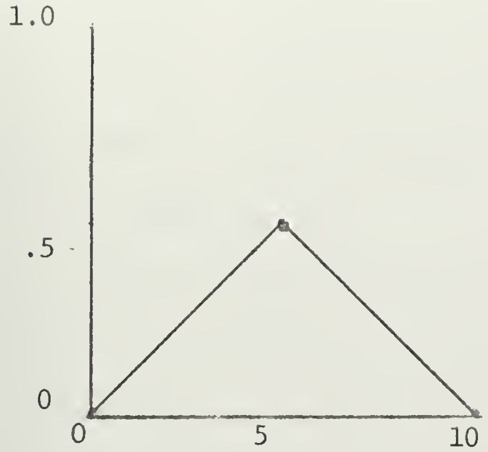
This subroutine is a random number generator provided in ref. 7. It starts with a seed of 65549 and generates random numbers between the values of 0.0 and 1.0.

4. Subroutine SETTE

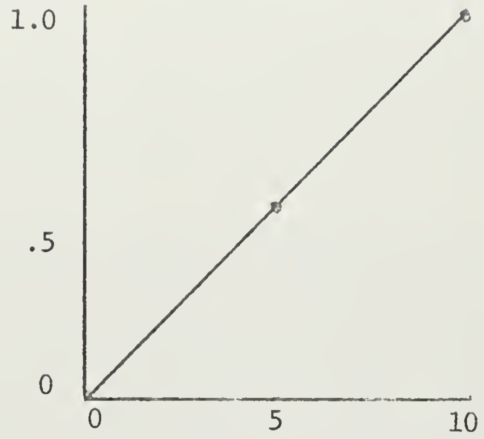
This subroutine enters a distribution of an activity's duration times with a random number and determines a te for the activity. The Y value of the cumulative distribution is searched sequentially until values bracketing the random number are found. Then the X value corresponding to these Y values is interpolated and the resulting X value is returned as the te. This is the inverse transformation method of generating stochastic variates as described in ref. 8.

5. Subroutine PLTHIS

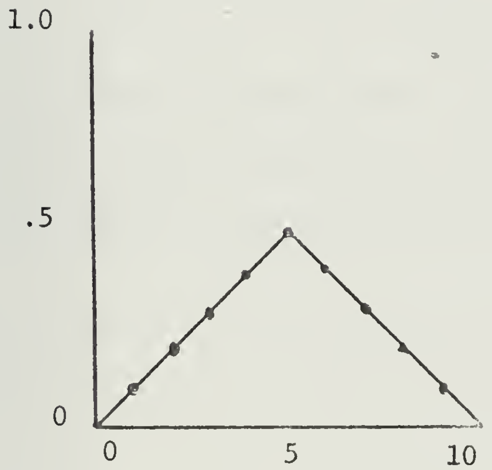
This subroutine fills the PLOT array for plotting the distribution of project completion times. It labels the plot of completion times, determines where the plot is to be placed in the display, and calls the DISPLY subroutine.



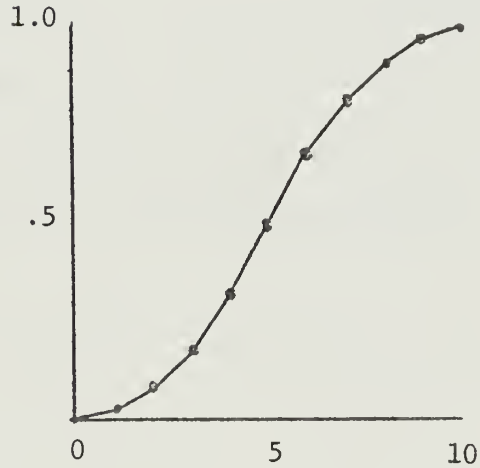
Triangular Distribution
Using 2 Lines



Resulting Cumulative Dist
of 2 Lines



Triangula· Distribution
Using 10 Lines



Resulting Cumulative Dist
of 10 Lines

FIGURE 12. Drawing a Frequency Distribution

6. <u>Subroutine DISPLY</u>

This subroutine is called to display the plot of project completion times and to display the distribution of an arc which has already been entered. It determines how many labels will fit on the X and Y axis, labels the axes, and plots the PLOT array.

7. <u>Subroutine CRIT</u>

This subroutine uses the ITCRT array and accentuates the arcs on the critical path. It is called after a mean time calculation and when performing a Monte Carlo analysis in the single step mode. Two extra lines are drawn along the arcs on the critical path. One line is displaced four raster units to the left and four up from the arc. The second line is displaced four raster units to the right and four up from the arc.

8. <u>Subroutine MARK</u>

This subroutine generates text above the arcs in the network. It displays the mean time te when doing a mean time calculation, the te when doing a Monte Carlo analyses on the single step mode, and the criticality indexes after the completion of a Monte Carlo analysis.

VIII. CONCLUDING REMARKS

The program described in this report allows a user to draw a PERT network on an IBM 2250 graphic display unit. The user can also draw distributions of activity duration times or he can enter them from punched cards. The network is then analyzed by the computer and the results of the analysis are displayed on the graphic display unit.

One of the uses of the program is to demonstrate for typical problems some of the differences between the usual PERT analysis and a Monte Carlo PERT analysis. In the usual PERT analysis the network is solved only once and the result is one critical path and a project completion time based on the mean times of activity durations. This is what is done when a network is analyzed for a "Mean Time Calculation" in this program. In a Monte Carlo analysis the project is simulated a large number of times to produce a distribution of project completion times. For each simulation the activity duration times may be different, with resulting differences in the critical path. A criticality index is associated with each activity as a measure of its chances of being on the critical path. A Monte Carlo analysis usually estimates a project completion time distribution with a mean time greater than that of the usual PERT analysis. Also, it usually shows that there are many potential critical paths.

Another use of the program is to allow the user to experiment with making changes in the network. Nodes and arcs can be added or deleted and the distributions of activity durations can be changed. The user can then analyze the changed network and see what effect the changes have on the criticality indexes and on the distribution of project completion times.

An improvement that could be made to the program would be to modify it to accept an entire network, with associated distributions, from punched cards. If the same network is to be analyzed and experimented on many times this would save the user the time required to reenter the network by light pen before each experiment.

Another improvement which could be made would be to add a subroutine which whenever called would plot whatever is displayed on the graphics unit on a Calcomp Plotter. This would give the user the capability of getting a hard copy output of the network, the plots of the distributions or any other display which he might find useful.

```
// EXEC FORTCLG,REGION.FORT=150K,REGION.GO=175K,TIME.GO=3
//FORT.SYSIN DD *
C
C      PERT-O-GRAPH
C
       COMMON/B/IX,IY,R
       COMMON/GS1/EVT,DIS,INTARY,IPT,NULL,I2250,IATL,IE,K1,K2,K3,K4,
      1INTC?
       COMMON/GS2/PLOT,YMAX,DEXT,REXT,TLO,THI,IW,ITM,LM,IHIS,IOX,IOY,IUX,
      1IUY,NPTS,IGDS
       DIMENSION EVT(50,20),NULL(1),INTARY(10),TX(50),DIS(50,20,3),
      1IPT(50,4),P(150),LOC(50,2),ICRIT(50,4),MID(2),TEXT23(4),
      2ITCRT(50,4)
       DIMENSION TEXT1(3),TEXT2(12),TEXT3(3),TEXT4(3),TEXT5(6),TEXT6(8),
      1TEXT7(5),TEXT8(6),TEXT9(6),TEXT10(6),TEXT11(2),TEXT12(6),TEXT13(4)
      2,TEXT14(4),TEXT15(2),TEXT16(2),PLN(2),TIM(2),IHIS(50),TEXT17(4),
      3TEXT18(6),TEXT19(5),TEXT20(6),TEXT21(4),TEXT22(5),PLOT(50,2)
       DIMENSION TEXT24(3),TEXT25(3),TEXT26(7),TEXT27(6),TEXT28(5),
      1TEXT30(6),TEXT31(6),TEXT32(5)
       DATA TEXT1/' ENT','ER N','ODE '/,TEXT2/' POS','ITIO','N LI','GHT '
      1,'PEN ','BEFO','RE P','RESS','ING ','FUNC','TION',' KEY'/,TEXT3/'
      2ENT','ER A','RC  '/,TEXT4/'PERT',' NET','WORK'/,TEXT5/'ARC ','FOR
      3','BEGI','NNIN','G EV','ENT '/,TEXT6/'INDI','CATE',' NOD','E, T','
      4HEN ','PRED','ECES','SOR '/,TEXT7/'ENTE','R DI','STRI','BUTI','ON
      5'/,TEXT8/'INDI','CATE',' BEG','INNI','NG E','VENT'/,TEXT9/'CUMU','
      6LATI','VE D','ISTR','IBUT','ION '/,TEXT10/'FREQ','UENC','Y DI','ST
      7RI','BUTI','ON  '/,TEXT11/'EXEC','UTE '/,TEXT12/'SAME',' DIS','TRI
      8B','UTIO','N AS',' ARC'/,TEXT21/'SING','LE E','XECU','TION'/,
      ?TEXT22/'COMP','LETE',' ANA','LYSI','S   '/,TEXT23/'CRIT','ICAL','
      8PAT','H'/,         TEXT13/'DELE','TE L','AST ','NODE'/,TEXT14/'DELE
      9','TE L','AST ','ARC '/,TEXT15/'REST','ART '/,TEXT16/'ANAL','YSES'
      A/,BLN/'    ','    '/,TEXT17/'MINI','MUM ','TIME',' ='/,TEXT18/'WID
      1T','H OF',' INC','REME','NTS ','='/,TEXT19/'NO. ','OF I','NCRE','M
      2ENT','S ='/,TEXT20/'MEAN',' TIM','E CA','LCUL','ATIO','N'/
       DATA TEXT24/'DELE','TE N','ODE'/,TEXT25/'DELE','TE A','RC'/,
      1TEXT26/'CHAN','GE C','OMMO','N DI','ST O','F AR','C'/,
      2TEXT27/'CHAN','GE O','NLY ','DIST',' OF ','ARC'/,TEXT28/'CRIT','IC
      3AL','ITY ','INDE','X'/,TEXT29/'QUIT'/,TEXT30/'DISP','LAY ','FREQ',
      4' DIS','T OF',' ARC'/,TEXT31/'DISP','LAY ','CUM.',' DIS','T OF','
      5ARC'/,TEXT32/'READ',' DIS','T FR','OM C','ARD'/
       DATA TX/'1 ','2 ','3 ','4 ', '5 ', '6 ', '7 ','8 ','9 ','10','11',
      1'12','13','14','15','16','17','18','19','20','21','22','23','24',
      2'25','26','27','28','29','30','31','32','33','34','35','36','37',
      3'38','39','40','41','42','43','44','45','46','47','48','49','50'/
       NULL(1)=6
       CALL INGSP(IGSP,NULL)
       CALL INDEV(IGSP,10,I2250)
       CALL TMDEV(I2250)
```

```
      CALL TMGSP(IGSP)
C
C     INITIALIZE GSP
C
      NULL(1)=6
      CALL INGSP(IGSP,NULL)
      CALL INDEV(IGSP,10,I2250)
      CALL SPEC(IGSP,1,40)
C
C     INITIALIZE DATA SETS
C
      CALL INGDS(I2250,IGDS1,1536,1,IGDS3,IGDS5)
      CALL INGDS(I2250,IGDS2,1536,1,IGDS4,IGDS6)
      CALL SDATM(IGDS1,3)
      CALL SDATM(IGDS2,3)
      CALL SCHAM(IGDS1,2)
      CALL SCHAM(IGDS2,3)
      CALL SDATM(IGDS5,3)
      CALL SCHAM(IGDS5,3)
      CALL SDATM(IGDS6,3)
      CALL SCHAM(IGDS6,3)
      CALL SDATM(IGDS3,3)
      CALL SCHAM(IGDS3,3)
      CALL SDATM(IGDS4,3)
      CALL SCHAM(IGDS4,3)
      CALL SGDSL(IGDS1,0,0,1024,1024,0,0,1024,1024)
      CALL SGDSL(IGDS2,0,0,1024,1024,0,0,1024,1024)
      CALL SGDSL(IGDS3,0,0,1024,1024,0,0,1024,1024)
      CALL SGDSL(IGDS4,0,0,1024,1024,0,0,1024,1024)
C
C     CREATE ATTENTION LEVEL, ENABLE FUNCTION KEYS
C
      CALL CRATL(I2250,IATL)
      CALL ENATN(IATL,0,-6,34)
      CALL MLPED(IATL,2,4,1)
      CALL SLPAT(IGDS2,1)
      CALL SLPAT(IGDS1,1)
      CALL SALRM(I2250)
C
C     SET UP GRAPHIC MESSAGES
C
      CALL PTEXT(IGDS1,TEXT4,12,NULL,IKY27,1,344,1000)
      CALL EXEC(IGDS1)
      IY=65549
      ITAB=0
      LM=0
    4 ICOR=0
      ICON=0
```

```
      K3=0
      KTEMP=0
      DO 601 N=1,50
      EVT(N,20)=0
      EVT(N,1)=0
      EVT(N,2)=0
      EVT(N,3)=0
      EVT(N,4)=0
      EVT(N,5)=0
      EVT(N,6)=0
      EVT(N,7)=0
      EVT(N,8)=0
  601 EVT(N,9)=0
C
C     DISPLAY TEXT FOR CALLING ROUTINES
C
  200 CALL STPOS(IGDS2,36,160)
      CALL PTEXT(IGDS2,TEXT1,12,NULL,IKY21,1,36,160)
      CALL PTEXT(IGDS2,TEXT3,12,NULL,IKY22,1,36,130)
      CALL PTEXT(IGDS2,TEXT5,24,NULL,IKY23,1,50,100)
      CALL EXEC(IGDS2)
      CALL STPOS(IGDS2,50,70)
      CALL PTEXT(IGDS2,TEXT11,8,NULL,IKY31,1,50,70)
      CALL PTEXT(IGDS2,TEXT13,16,NULL,IKY33,1,500,40)
      CALL PTEXT(IGDS2,TEXT15,8,NULL,IKY35,1,500,100)
      CALL PTEXT(IGDS2,TEXT24,11,NULL,IKY44,1,500,160)
      CALL EXEC(IGDS2)
      CALL STPOS(IGDS2,500,130)
      CALL PTEXT(IGDS2,TEXT25,10,NULL,IKY45,1,500,130)
      CALL PTEXT(IGDS2,TEXT26,25,NULL,IKY46,1,50,40)
      CALL PTEXT(IGDS2,TEXT27,23,NULL,IKY47,1,500,70)
      CALL EXEC(IGDS2)
      CALL STPOS(IGDS2,50,190)
      CALL PTEXT(IGDS2,TEXT29,4,NULL,IKY49,1,50,190)
      CALL PTEXT(IGDS2,TEXT30,16,NULL,IKY50,1,50,10)
      CALL PTEXT(IGDS2,TEXT31,24,NULL,IKY51,1,500,10)
      CALL EXEC(IGDS2)
      K3=KTEMP
C
C     CALL NEXT ROUTINE WITH LIGHT PEN
C
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      CALL RESET(IGDS2)
      IF(INTARY(2).EQ.IKY21)GO TO 201
      IF(INTARY(2).EQ.IKY22)GO TO 202
      IF(INTARY(2).EQ.IKY23)GO TO 203
      IF(INTARY(2).EQ.IKY31)GO TO 600
      IF(INTARY(2).EQ.IKY33)GO TO 450
```

```
      IF(INTARY(2).EQ.IKY35)GO TO 510
      IF(INTARY(2).EQ.IKY46)GO TO 800
      IF(INTARY(2).EQ.IKY44)GO TO 405
      IF(INTARY(2).EQ.IKY45)GO TO 409
      IF(INTARY(2).EQ.IKY47)GO TO 900
      IF(INTARY(2).EQ.IKY49)GO TO 300
      IF(INTARY(2).EQ.IKY50)GO TO 1900
      IF(INTARY(2).EQ.IKY51)GO TO 1800
      GO TO 200
C
C     PLOT NODE
C
  201 ICOR=ICOR+1
      CALL PTEXT(IGDS2,TEXT2,48,NULL,IKY24,1,176,25)
      CALL EXEC(IGDS2)
      CALL MLITS(IATL,4,4)
      CALL RQATN(IATL,INTCD,2,NULL,4)
      CALL LOCPN(IGDS1,LX,LY)
      CALL PTEXT(IGDS1,TX(ICOR),2,ICOR,NULL,NULL,LX,LY)
      LOC(ICOR,1)=LX+21
      LOC(ICOR,2)=LY
      CALL EXEC(IGDS1)
      CALL RESET(IGDS2)
      CALL MLITS(IATL,2)
      GO TO 200
C
C     PLOT ARC
C
  202 CALL PTEXT(IGDS2,TEXT6,32,NULL,IKY25,1,302,970)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      CALL SALRM(I2250)
      K1=INTARY(4)
      LX=INTARY(8)-42
      CALL STPOS(IGDS1,LX,INTARY(9))
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      K2=INTARY(4)
      IC1=K1*100+K2
      CALL PLINE(IGDS1,INTARY(8),INTARY(9),IC1)
      CALL EXEC(IGDS1)
      CALL RESET(IGDS2)
      CALL PTEXT(IGDS2,TEXT7,19,NULL,IKY26,1,50,40)
      CALL PTEXT(IGDS2,TEXT12,24,NULL,IKY32,1,50,70)
      CALL PTEXT(IGDS2,TEXT14,16,NULL,IKY34,1,50,100)
      CALL PTEXT(IGDS2,TEXT32,19,NULL,IKY52,1,50,10)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      CALL RESET(IGDS2)
```

```
      IF(INTARY(2).EQ.IKY32)GO TO 209
      IF(INTARY(2).EQ.IKY34)GO TO 470
      IF(INTARY(2).EQ.IKY52)K14=1
      GO TO 204
C
C     PLOT ARC FOR BEGINNING EVENT
C
  203 CALL PTEXT(IGDS2,TEXT8,24,NULL,IKY28,1,365,20)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      LX=INTARY(8)-42
      K1=INTARY(4)
      K2=0
      CALL STPOS(IGDS1,LX,INTARY(9))
      LX=LX-60
      IC1=K1*100
      CALL PLINE(IGDS1,LX,INTARY(9),IC1)
      CALL EXEC(IGDS1)
      CALL RESET(IGDS2)
      CALL PTEXT(IGDS2,TEXT7,19,NULL,IKY26,1,50,40)
      CALL PTEXT(IGDS2,TEXT12,24,NULL,IKY32,1,50,70)
      CALL PTEXT(IGDS2,TEXT14,16,NULL,IKY34,1,50,100)
      CALL PTEXT(IGDS2,TEXT32,19,NULL,IKY52,1,50,10)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      CALL RESET(IGDS2)
      IF(INTARY(2).EQ.IKY32)GO TO 209
      IF(INTARY(2).EQ.IKY34)GO TO 470
      IF(INTARY(2).EQ.IKY52)K14=1
  204 K3=K3+1
      KTEMP=K3
      IF(EVT(K1,1).EQ.0.)GO TO 220
      IF(EVT(K1,3).EQ.0.)GO TO 230
      IF(EVT(K1,5).EQ.0.)GO TO 240
      EVT(K1,7)=K2
      EVT(K1,4)=K3
      IF(K14.EQ.1)GO TO 2210
      K4=4
      GO TO 205
C
C     READ DIST FROM PUNCHED CARDS
C
 2210 K14=0
 2200 READ(5,2201)IE
 2201 FORMAT(I6)
      DO 2205 I=1,IE
      READ(5,2202)DIS(K3,I,2),DIS(K3,I,1)
 2202 FORMAT(F6.1,F6.3)
```

```
 2205 CONTINUE
      GO TO 200
C
C     CHANGE ONLY DISTRIBUTION OF ONE ARC
C     ANY OTHERS USING SAME DISTRIBUTION ARE UNCHANGED
C
  900 CALL PTEXT(IGDS2,TEXT27,23,NULL,IKY47,1,500,70)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      K2=INTARY(4)
      K1=(K2/100)*100
      PK2=K2-K1
      K1=K1/100
      KTEMP=K3
      CALL RESET(IGDS2)
      IF(EVT(K1,1).EQ.PK2)GO TO 910
      IF(EVT(K1,3).EQ.PK2)GO TO 920
      IF(EVT(K1,5).EQ.PK2)GO TO 930
      K3=IPT(K1,4)
      L=4
      GO TO 940
  910 K3=IPT(K1,1)
      L=1
      GO TO 940
  920 K3=IPT(K1,2)
      L=2
      GO TO 940
  930 K3=IPT(K1,3)
      L=3
C
C     CHECK IF ANOTHER ARC IS USING SAME DISTRIBUTION
C
  940 DO 950 I=1,ICOR
      IF(EVT(I,20).EQ.1.)GO TO 950
      DO 951 J=1,4
      IF(IPT(I,J).EQ.K3)GO TO 960
      GO TO 951
  960 IF((I.EQ.K1).AND.(J.EQ.L))GO TO 951
      K3=KTEMP+1
      IPT(K1,L)=K3
      GO TO 952
  951 CONTINUE
  950 CONTINUE
  952 CALL PTEXT(IGDS2,TEXT12,24,NULL,IKY32,1,50,70)
      CALL PTEXT(IGDS2,TEXT7,19,NULL,IKY26,1,50,40)
      CALL PTEXT(IGDS2,TEXT32,19,NULL,IKY52,1,50,10)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,INTARY,34)
```

```
      CALL RESET(IGDS2)
      IF(INTARY(2).EQ.IKY26)GO TO 205
      IF(INTARY(2).EQ.IKY52)GO TO 2200
      K11=1
      GO TO 209
  970 IPT(K1,L)=KK3
      K11=0
      GO TO 200
C
C     DELETE A NODE
C
  405 CALL PTEXT(IGDS2,TEXT24,11,NULL,IKY44,1,500,160)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      ITC=INTARY(4)
      CALL OMIT(IGDS1,ITC,NULL)
      EVT(ITC,20)=1.
      CALL RESET(IGDS2)
      GO TO 200
C
C     DELETE AN ARC
C
  409 CALL PTEXT(IGDS2,TEXT25,10,NULL,IKY45,1,500,130)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      CALL OMIT(IGDS1,INTARY(4))
      KK2=INTARY(4)
      KK1=(KK2/100)*100
      PK2=KK2-KK1
      KK1=KK1/100
      IF(EVT(KK1,1).EQ.PK2)GO TO 410
      IF(EVT(KK1,3).EQ.PK2)GO TO 420
      IF(EVT(KK1,5).EQ.PK2)GO TO 430
      GO TO 440
  410 EVT(KK1,1)=EVT(KK1,3)
      IPT(KK1,1)=IPT(KK1,2)
  420 EVT(KK1,3)=EVT(KK1,5)
      IPT(KK1,2)=IPT(KK1,3)
  430 EVT(KK1,5)=EVT(KK1,7)
      IPT(KK1,3)=IPT(KK1,4)
  440 EVT(KK1,7)=0.
      IPT(KK1,4)=0
      CALL RESET(IGDS2)
      GO TO 200
C
C     DISPLAY FREQUENCY DISTRIBUTION OF AN ARC
C
 1900 CALL PTEXT(IGDS2,TEXT30,24,NULL,IKY50,1,500,10)
```

```
      CALL EXEC(IGDS2)
      K12=1
      GO TO 805
 1905 K12=0
      PLOT(1,1)=0.
      DEXT=DIS(K3,1,2)
      PLOT(1,2)=DEXT
      DO 1950 I=2,20
      PLOT(I,2)=DIS(K3,I,2)
      PLOT(I,1)=DIS(K3,I,3)
      IF(DIS(K3,I,1).GT..999)GO TO 1955
      GO TO 1950
 1955 NPTS=I
      REXT=PLOT(I,2)
      GO TO 1960
 1950 CONTINUE
 1960 IOX=0
      IOY=0
      IUX=450
      IUY=200
      YMAX=0.
      DO 1970 I=1,NPTS
 1970 IF(PLOT(I,1).GT.YMAX)YMAX=PLOT(I,1)
      IGDS=IGDS2
      CALL DISPLY(NULL,I2250)
      CALL MLITS(IATL,4,3)
      CALL RQATN(IATL,INTCD,2,NULL,3)
      CALL RESET(IGDS2)
      CALL SGDSL(IGDS2,0,0,1024,1024,0,0,1024,1024)
      CALL MLITS(IATL,2)
      GO TO 200
C
C     DISPLAY CUMULATIVE DISTRIBUTION OF AN ARC
C
 1800 CALL PTEXT(IGDS2,TEXT31,24,NULL,IKY51,1,500,10)
      CALL EXEC(IGDS2)
      K13=1
      GO TO 805
 1805 K13=0
      YMAX=1.0
      DEXT=DIS(K3,1,2)
      PLOT(1,2)=DEXT
      PLOT(1,1)=0.
      NPTS=1
      DO 1860 I=2,20
      PLOT(I,2)=DIS(K3,I,2)
      PLOT(I,1)=DIS(K3,I,1)
      NPTS=NPTS+1
```

```
      IF(PLOT(I,1).NE.1.0)GO TO 1860
      REXT=PLOT(I,2)
      GO TO 1810
 1860 CONTINUE
 1810 IOX=0
      IOY=0
      IUX=450
      IUY=200
      ICDS=IGDS2
      CALL DISPLY(NULL,I2250)
      CALL MLITS(IATL,4,3)
      CALL ROATN(IATL,INTCD,2,NULL,3)
      CALL RESET(IGDS2)
      CALL SGDSL(IGDS2,0,0,1024,1024,0,0,1024,1024)
      CALL MLITS(IATL,2)
      GO TO 200
C
C     CHANGE ALL USING SAME DISTRIBUTION
C
  800 CALL PTEXT(IGDS2,TEXT26,25,NULL,IKY46,1,500,40)
      CALL EXEC(IGDS2)
  805 CALL ROATN(IATL,INTCD,2,INTARY,34)
      K2=INTARY(4)
      K1=(K2/100)*100
      PK2=K2-K1
      K1=K1/100
      KTEMP=K3
      IF(EVT(K1,1).EQ.PK2)GO TO 810
      IF(EVT(K1,3).EQ.PK2)GO TO 820
      IF(EVT(K1,5).EQ.PK2)GO TO 830
      K3=IPT(K1,4)
      GO TO 840
  810 K3=IPT(K1,1)
      GO TO 840
  820 K3=IPT(K1,2)
      GO TO 840
  830 K3=IPT(K1,3)
  840 IF(K12.EQ.1)GO TO 1905
      IF(K13.EQ.1)GO TO 1805
      CALL PTEXT(IGDS2,TEXT12,24,NULL,IKY32,1,50,70)
      CALL PTEXT(IGDS2,TEXT7,19,NULL,IKY26,1,50,40)
      CALL PTEXT(IGDS2,TEXT32,19,NULL,IKY52,1,50,10)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      CALL RESET(IGDS2)
      K10=1
      IF(INTARY(2).EQ.IKY26)GO TO 205
      IF(INTARY(2).EQ.IKY52)GO TO 2200
```

```
      GO TO 209
  850 K10=0
      DO 860 I=1,ICOR
      DO 861 J=1,4
      IF(IPT(I,J).NE.K3)GO TO 861
      IPT(I,J)=KK3
  861 CONTINUE
  860 CONTINUE
      GO TO 200
C
C     RESTART
C
  510 CALL RESET(IGDS1)
      CALL PTEXT(IGDS1,TEXT4,12,NULL,IKY27,1,344,1000)
      CALL EXEC(IGDS1)
      DO 511 I=1,K3
      DO 512 L=1,2
      DO 513 K=1,20
      DIS(I,K,L)=0.0
  513 CONTINUE
  512 CONTINUE
  511 CONTINUE
      DO 514 I=1,ICOR
      DO 515 I1=1,4
  515 CRIT(I,I1)=0
  514 CONTINUE
      GO TO 4
C
C     DELETE LAST NODE
C
  450 CALL RESET(IGDS1,ICOR)
      ICOR=ICOR-1
      GO TO 200
C
C     DELETE LAST ARC
C
  470 CALL RESET(IGDS1,IC1)
      GO TO 200
C
C     DISTRIBUTION PREVIOUSLY DESCRIBED
C
  209 CALL PTEXT(IGDS2,TEXT12,24,NULL,IKY32,1,50,70)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      KK2=INTARY(4)
      CALL SALRM(I225C)
      KK1=(KK2/100)*100
      PK2=KK2-KK1
```

```
      KK1=KK1/100
      CALL RESET(IGDS2)
      IF(EVT(KK1,1).EQ.PK2)GO TO 210
      IF(EVT(KK1,3).EQ.PK2)GO TO 211
      IF(EVT(KK1,5).EQ.PK2)GO TO 212
      KK3=IPT(KK1,4)
      GO TO 213
  210 KK3=IPT(KK1,1)
      GO TO 213
  211 KK3=IPT(KK1,2)
      GO TO 213
  212 KK3=IPT(KK1,3)
  213 IF(K10.EQ.1)GO TO 850
      IF(K11.EQ.1)GO TO 970
      IF(EVT(K1,1).EQ.0.)GO TO 221
      IF(EVT(K1,3).EQ.0.)GO TO 231
      IF(EVT(K1,5).EQ.0.)GO TO 241
      EVT(K1,7)=K2
      IPT(K1,4)=KK3
      GO TO 200
  221 EVT(K1,1)=K2
      IPT(K1,1)=KK3
      GO TO 200
  231 EVT(K1,3)=K2
      IPT(K1,2)=KK3
      GO TO 200
  241 EVT(K1,5)=K2
      IPT(K1,3)=KK3
      GO TO 200
  220 EVT(K1,1)=K2
      IPT(K1,1)=K3
      IF(K14.EQ.1)GO TO 2210
      K4=1
      GO TO 205
  230 EVT(K1,3)=K2
      IPT(K1,2)=K3
      IF(K14.EQ.1)GO TO 2210
      K4=2
      GO TO 205
  240 EVT(K1,5)=K2
      IPT(K1,3)=K3
      IF(K14.EQ.1)GO TO 2210
      K4=3
C
C     CHOOSE TYPE OF DISTRIBUTION
C
  205 CALL OMIT(IGDS1)
      KTEMP=K3
```

```
      CALL PTEXT(IGDS2,TEXT9,24,NULL,IKY29,1,365,940)
      CALL PTEXT(IGDS2,TEXT10,24,NULL,IKY30,1,365,1000)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      CALL RESET(IGDS2)
      IF(INTARY(2).EQ.IKY29)GO TO 301
C
C     ENTER FREQUENCY DISTRIBUTION
C
  400 CALL STPOS(IGDS3,365,1000)
      CALL PTEXT(IGDS3,TEXT10,24,NULL,NULL,1,365,1000)
      CALL EXEC(IGDS3)
      CALL INCL(IGDS3)
      CALL DIST(IGDS3,IGDS4)
      YY=DIS(K3,1,1)
      DIS(K3,1,3)=YY
      DO 402 I=2,IE
      DIS(K3,I,3)=DIS(K3,I,1)
      X=DIS(K3,I,2)
      X1=DIS(K3,I-1,2)
      Y=DIS(K3,I,1)
      Y1=YY
      YY=Y
      DIS(K3,I,1)=(X-X1)*(Y1+.5*(Y-Y1))+DIS(K3,I-1,1)
  402 CONTINUE
      CALL RESET(IGDS3)
      CALL RESET(IGDS4)
      IF(DIS(K3,IE,1).EQ.1.0)GO TO 200
      X=DIS(K3,IE,1)
      DO 401 I=1,IE
  401 DIS(K3,I,1)=DIS(K3,I,1)/X
      CALL EXEC(IGDS1)
      CALL INCL(IGDS1)
      KK3=K3
      IF(K10.EQ.1)GO TO 850
      GO TO 200
C
C     ENTER CUMULATIVE DISTRIBUTION
C
  301 CALL STPOS(IGDS3,365,1000)
      CALL PTEXT(IGDS3,TEST9,24,NULL,NULL,1,365,1000)
      CALL EXEC(IGDS3)
      CALL INCL(IGDS3)
      CALL DIST(IGDS3,IGDS4)
      CALL RESET(IGDS3)
      CALL RESET(IGDS4)
      CALL EXEC(IGDS1)
      CALL INCL(IGDS1)
```

```
      IF(K10.EQ.1)GO TO 850
      GO TO 200
 1200 ISW=1
      CALL MLITS(IATL,2)
      INTARY(2)=0
      NT=ICOR
      KT=0
 1605 KT=KT+1
      KS=0
      KR=0
      IF(KT.GT.NT)GO TO 100
      IF(EVT(KT,20).EQ.1.)GO TO 1605
      IF(EVT(KT,1).EQ.0.)GO TO 1610
 1606 KS=KS+1
      KR=KR+2
      KP=IPT(KT,KS)
      CALL MEAN(KP,DIS,TMN)
      EVT(KT,KR)=TMN
      IF(EVT(KT,KR+1).EQ.0.)GO TO 1605
      GO TO 1606
 1610 KP=IPT(KT,1)
      CALL MEAN(KP,DIS,TMN)
      EVT(KT,9)=TMN
      GO TO 1605
C
C     ENTER MEAN CALCULATION
C
 1250 ISW=0
      CALL MLITS(IATL,4,3)
      CALL BCNV(EVT(1,18),MID,102,8,1)
      CALL STPOS(IGDS2,390,40)
      CALL PTEXT(IGDS2,MID,8,2)
      CALL STPOS(IGDS2,350,960)
      CALL PTEXT(IGDS2,TEXT23,13,NULL,IKY43,1,350,960)
      CALL EXEC(IGDS2)
      CALL STPOS(IGDS1,540,960)
      CALL PLINE(IGDS1,610,960,NULL,IKY70)
      CALL EXEC(IGDS1)
      CALL MARK(EVT,LOC,IGDS2,NT)
      CALL EXEC(IGDS2)
      CALL CRIT(ITCRT,LOC,IGDS1,EVT,NT)
      CALL EXEC(IGDS1)
      CALL RQATN(IATL,INTCD,2,NULL,3)
      CALL RESET(IGDS2,NULL,IKY43)
      CALL RESET(IGDS1,NULL,IKY70)
      CALL MLITS(IATL,2)
      DO 1251 I=1,NT
 1251 EVT(I,9)=0.
```

```
      GO TO 620
C
C     CHOOSE TYPE OF EXECUTION
C
  600 CALL PTEXT(IGDS2,TEXT11,8,NULL,IKY31,1,50,70)
      CALL PTEXT(IGDS2,TEXT16,8,NULL,IKY36,1,240,70)
      CALL PTEXT(IGDS2,BLN,4,1,NULL,1,170,70)
      CALL PTEXT(IGDS2,TEXT20,24,NULL,IKY40,1,50,40)
      CALL EXEC(IGDS2)
  620 CALL ICURS(IGDS2,1,NULL,1)
      CALL EXEC(IGDS2)
      NT=ICOR
      DO 604 I=1,NT
      DO 607 I1=1,4
      [illegible](I,I1)=0
  607 [illegible],I1)=0
  604 CONTINUE
      DO 603 I=1,150
  603 P(I)=0.0
      CALL MLITS(IATL,4,1)
      CALL ROATN(IATL,INTCD,2,INTARY,1,34)
      CALL RCURS(IGDS2)
      IF(INTARY(2).EQ.IKY40)GO TO 1200
      CALL GSPRD(IGDS2,TIM,4,1,ITIM,1)
      CALL STPOS(IGDS2,170,70)
      CALL PTEXT(IGDS2,TIM,4,NULL,NULL,1,170,70)
      CALL EXEC(IGDS2)
      CALL BCNV(TIM,TM,202,4,0)
      IT[illegible]
      CALL PTEXT(IGDS2,TEXT17,14,NULL,IKY37,1,50,130)
      CALL PTEXT(IGDS2,BLN,8,3,NULL,1,260,130)
      CALL PTEXT(IGDS2,TEXT18,21,NULL,IKY38,1,550,130)
      CALL PTEXT(IGDS2,BLN,8,4,NULL,1,858,130)
      CALL PTEXT(IGDS2,TEXT19,20,NULL,IKY39,1,50,100)
      CALL PTEXT(IGDS2,BLN,8,5,NULL,1,[illegible]35,100)
      CALL ICURS(IGDS2,3,NULL,1)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,NULL,1)
      CALL GSPRD(IGDS2,TIM,8,1,ITIM,3)
      CALL STPOS(IGDS2,260,130)
      CALL PTEXT(IGDS2,TIM,8,NULL,NULL,1,260,130)
      CALL EXEC(IGDS2)
      CALL BCNV(TIM,TLO,202,8,1)
      CALL RCURS(IGDS2)
      CALL ICURS(IGDS2,4,NULL,1)
      CALL EXEC(IGDS2)
      CALL ROATN(IATL,INTCD,2,NULL,1)
      CALL GSPRD(IGDS2,TIM,8,1,ITIM,4)
```

```
      CALL STPOS(IGDS2,858,130)
      CALL PTEXT(IGDS2,TIM,8,NULL,NULL,1,858,130)
      CALL EXEC(IGDS2)
      CALL BCNV(TIM,THI,202,8,1)
      CALL RCURS(IGDS2)
      CALL ICURS(IGDS2,5,NULL,1)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,NULL,1)
      CALL GSPRD(IGDS2,TIM,8,1,ITIM,5)
      CALL STPOS(IGDS2,335,100)
      CALL PTEXT(IGDS2,TIM,8,NULL,NULL,1,335,100)
      CALL EXEC(IGDS2)
      CALL BCNV(TIM,WID,202,8,1)
      CALL RCURS(IGDS2)
      CALL MLITS(IATL,2)
      IW=WID
      DO 602 I=1,IW
  602 IHIS(I)=0
      SUMM=0.0
      SUMD=0.0
C
C     FILL EVT ARRAY FOR CRITICAL PATH ANALYSIS
C
 1730 CALL PTEXT(IGDS2,TEXT21,16,NULL,IKY41,1,50,10)
      CALL PTEXT(IGDS2,TEXT22,17,NULL,IKY42,1,500,10)
      CALL EXEC(IGDS2)
      CALL RQATN(IATL,INTCD,2,INTARY,34)
      IF(INTARY(2).EQ.IKY41)IGO=1
      IF(INTARY(2).EQ.IKY42)IGO=0
      DO 199 IREP=1,ITM
      DO 198 I=1,NT
  198 EVT(I,9)=0.0
      KT=0
  605 KT=KT+1
      KS=0
      KR=0
      IF(KT.GT.NT)GO TO 100
      IF(EVT(KT,20).EQ.1.)GO TO 605
      IF(EVT(KT,1).EQ.0.)GO TO 610
  606 KS=KS+1
      KR=KR+2
      IX=IY
      CALL RAND
      KP=IPT(KT,KS)
      CALL SETTE(KP,R,TE)
      EVT(KT,KP)=TE
      IF(EVT(KT,(KP+1)).EQ.0.)GO TO 605
      GO TO 606
```

```
610  IX=IY
     CALL RAND
     KP=IPT(KT,1)
     CALL SETTE(KP,R,TE)
     EVT(KT,9)=TE
     GO TO 605
C
C    CRITICAL PATH ANALYSIS
C
100  K=2
     P(1)=1
     P(2)=EVT(1,1)
     N=P(2)
103  IF(EVT(N,9))104,104,105
104  K=K+1
     P(K)=EVT(N,1)
     N=P(K)
     GO TO 103
105  TE1=EVT(N,9)
     K=K-1
     N=P(K)
     TE5=TE1+EVT(N,2)
     IF(EVT(N,3))106,106,107
106  EVT(N,9)=TE5
     GO TO 115
107  K=K+1
     P(K)=EVT(N,3)
     N=P(K)
     IF(EVT(N,9))104,104,108
108  TE2=EVT(N,9)
     K=K-1
     N=P(K)
     TE6=TE2+EVT(N,4)
     IF(EVT(N,5))114,114,109
109  K=K+1
     P(K)=EVT(N,5)
     N=P(K)
     IF(EVT(N,9))104,104,110
110  TE3=EVT(N,9)
     K=K-1
     N=P(K)
     TE7=TE3+EVT(N,6)
     IF(EVT(N,7))113,113,111
111  K=K+1
     P(K)=EVT(N,7)
     N=P(K)
     IF(EVT(N,9))104,104,112
112  TE4=EVT(N,9)
```

```
      K=K-1
      N=P(K)
      TE8=TE4+EVT(N,8)
      IF(TE5.GT.TE6)TE6=TE5
      IF(TE6.GT.TE7)TE7=TE6
      IF(TE7.GT.TE8)TE8=TE7
      EVT(N,9)=TE8
      GO TO 115
  113 IF(TE5.GT.TE6)TE6=TE5
      IF(TE6.GT.TE7)TE7=TE6
      EVT(N,9)=TE7
      GO TO 115
  114 IF(TE5.GT.TE6)TE6=TE5
      EVT(N,9)=TE6
  115 IF(K-1)117,117,116
  116 K=K-1
      N=P(K)
      GO TO 103
  117 DO 118 N=1,NT
      EVT(N,10)=0
      EVT(N,11)=0
      EVT(N,12)=0
      EVT(N,13)=0
      EVT(N,14)=0
      EVT(N,15)=0
      EVT(N,16)=0
      EVT(N,17)=0
  118 EVT(N,18)=0
C
C     IMMEDIATE SUCCESSOR
C
      DO 150 N=1,NT
      I=EVT(N,1)
      J1=EVT(N,3)
      K=EVT(N,5)
      L=EVT(N,7)
      IF(I)150,150,119
  119 IF(EVT(I,10))120,120,121
  120 EVT(I,10)=N
      EVT(I,11)=EVT(N,2)
      GO TO 126
  121 IF(EVT(I,12))122,122,123
  122 EVT(I,12)=N
      EVT(I,13)=EVT(N,2)
      GO TO 126
  123 IF(EVT(I,14))124,124,125
  124 EVT(I,14)=N
      EVT(I,15)=EVT(N,2)
```

```
      GO TO 126
  125 EVT(I,16)=N
      EVT(I,17)=EVT(N,2)
  126 IF(J1)150,150,127
  127 IF(EVT(J1,10))128,128,129
  128 EVT(J1,10)=N
      EVT(J1,11)=EVT(N,4)
      GO TO 134
  129 IF(EVT(J1,12))130,130,131
  130 EVT(J1,12)=N
      EVT(J1,13)=EVT(N,4)
      GO TO 134
  131 IF(EVT(J1,14))132,132,133
  132 EVT(J1,14)=N
      EVT(J1,15)=EVT(N,4)
      GO TO 134
  133 EVT(J1,16)=N
      EVT(J1,17)=EVT(N,4)
  134 IF(K)150,150,135
  135 IF(EVT(K,10))136,136,137
  136 EVT(K,10)=N
      EVT(K,11)=EVT(N,6)
      GO TO 142
  137 IF(EVT(K,12))138,138,139
  138 EVT(K,12)=N
      EVT(K,13)=EVT(N,6)
      GO TO 142
  139 IF(EVT(K,14))140,140,141
  140 EVT(K,14)=N
      EVT(K,15)=EVT(N,6)
      GO TO 142
  141 EVT(K,16)=N
      EVT(K,17)=EVT(N,6)
  142 IF(L)150,150 ,143
  143 IF(EVT(L,10))144,144,145
  144 EVT(L,10)=N
      EVT(L,11)=EVT(N,8)
      GO TO 150
  145 IF(EVT(L,12))146,146,147
  146 EVT(L,12)=N
      EVT(L,13)=EVT(N,8)
      GO TO 150
  147 IF(EVT(L,14))148,148,149
  148 EVT(L,14)=N
      EVT(L,15)=EVT(N,8)
      GO TO 150
  149 EVT(L,16)=N
      EVT(L,17)=EVT(N,8)
```

```
150 CONTINUE
    K=NT
    EVT(1,18)=EVT(1,9)
    N=EVT(1,1)
151 IF(EVT(N,18))152,152,159
152 IF(EVT(N,16))153,153,173
153 IF(EVT(N,14))154,154,166
154 IF(EVT(N,12))155,155,161
155 M=EVT(N,10)
    IF(EVT(M,18))156,156,157
156 K=K+1
    P(K)=N
    N=M
    GO TO 152
157 EVT(N,18)=EVT(M,18)-EVT(N,11)
158 N=P(K)
    IF(N)159,159,151
159 DO 160 N9=1,NT
    N=N9
    IF(EVT(N,20).EQ.1.)GO TO 160
    IF(EVT(N,18))152,152,160
160 CONTINUE
    GO TO 182
161 M1=EVT(N,10)
    IF(EVT(M1,18))162,162,163
162 K=K+1
    P(K)=N
    N=M1
    GO TO 152
163 M2=EVT(N,12)
    IF(EVT(M2,18))164,164,165
164 K=K+1
    P(K)=N
    N=M2
    GO TO 152
165 TL1=EVT(M1,18)-EVT(N,11)
    TL2=EVT(M2,18)-EVT(N,13)
    IF(TL1.LT.TL2)TL2=TL1
    EVT(N,18)=TL2
    GO TO 158
166 M1=EVT(N,10)
    IF(EVT(M1,18))167,167,168
167 K=K+1
    P(K)=N
    N=M1
    GO TO 152
168 M2=EVT(N,12)
    IF(EVT(M2,18))169,169,170
```

```
169 K=K+1
    P(K)=N
    N=M2
    GO TO 152
170 M3=EVT(N,14)
    IF(EVT(M3,18))171,171,172
171 K=K+1
    P(K)=N
    N=M3
    GO TO 152
172 TL1=EVT(M1,18)-EVT(N,11)
    TL2=EVT(M2,18)-EVT(N,13)
    TL3=EVT(M3,18)-EVT(N,15)
    IF(TL1.LT.TL2)TL2=TL1
    IF(TL2.LT.TL3)TL3=TL2
    EVT(N,18)=TL3
    GO TO 158
173 M1=EVT(N,10)
    IF(EVT(M1,18))174,174,175
174 K=K+1
    P(K)=N
    N=M1
    GO TO 152
175 M2=EVT(N,12)
    IF(EVT(M2,18))176,176,177
176 K=K+1
    P(K)=N
    N=M2
    GO TO 152
177 M3=EVT(N,14)
    IF(EVT(M3,18))178,178,179
178 K=K+1
    P(K)=N
    N=M3
    GO TO 152
179 M4=EVT(N,16)
    IF(EVT(M4,18))180,180,181
180 K=K+1
    P(K)=N
    N=M4
    GO TO 152
181 TL1=EVT(M1,18)-EVT(N,11)
    TL2=EVT(M2,18)-EVT(N,13)
    TL3=EVT(M3,18)-EVT(N,15)
    TL4=EVT(M4,18)-EVT(N,17)
    IF(TL1.LT.TL2)TL2=TL1
    IF(TL2.LT.TL3)TL3=TL2
    IF(TL3.LT.TL4)TL4=TL3
```

```
      EVT(N,18)=TL4
      GO TO 158
  182 DO 183 N=1,NT
  183 EVT(N,19)=EVT(N,18)-EVT(N,9)
C
C     TABULATE ARCS ON CRITICAL PATH
C
      DO 185 N=1,NT
      IF(EVT(N,20).EQ.1.)GO TO 185
  184 IP1=-1
      IP2=0
      I1=0
  191 IP1=IP1+2
      IF(IP1.GT.7)GO TO 185
      IP2=IP2+2
      I1=I1+1
      IF(EVT(N,IP1))186,186,193
  193 CK=EVT(N,IP1)
      IF(EVT(CK,19).GT..01)GO TO 191
  190 IF(((EVT(N,18)-EVT(N,IP2))-EVT(CK,18)).LT..01)GO TO 192
      GO TO 191
  192 IF(EVT(CK,19).GT..01)GO TO 191
      ICRIT(N,I1)=ICRIT(N,I1)+1
      ITCRT(N,I1)=1
      GO TO 191
  194 ICRIT(N,I1)=ICRIT(N,I1)+1
      ITCRT(N,I1)=1
      GO TO 185
  186 IF(IP1.NE.1)GO TO 185
      IF(EVT(N,19))194,194,185
  185 CONTINUE
      IF(ISW.EQ.1)GO TO 1250
      SUMM=SUMM+EVT(1,18)
      SUMD=SUMD+EVT(1,18)**2
      IX=(EVT(1,18)-TLO)/THI
      IF(IX.LT.1)GO TO 196
      IF(IX.GE.IW)GO TO 197
      IHIS(IX+1)=IHIS(IX+1)+1
      GO TO 195
  196 IHIS(1)=IHIS(1)+1
      GO TO 195
  197 IHIS(IW)=IHIS(IW)+1
  195 IF(IGO.LT.1)GO TO 199
      CALL STPOS(IGDS2,350,960)
      CALL PTEXT(IGDS2,TEXT23,13,NULL,IKY43,1,350,960)
      CALL EXEC(IGDS2)
      CALL STPOS(IGDS1,540,960)
      CALL PLINE(IGDS1,610,960,NULL,IKY70)
```

```
      CALL EXEC(IGDS1)
      CALL MARK(EVT,LOC,IGDS2,NT)
      CALL EXEC(IGDS2)
      CALL MLITS(IATL,4,3)
      CALL RQATN(IATL,INTCD,2,NULL,3)
      CALL MLITS(IATL,2)
      CALL CRIT(ITCRT,LOC,IGDS1,EVT,NT)
      CALL EXEC(IGDS1)
      CALL MLITS(IATL,4,5)
      CALL RQATN(IATL,INTCD,2,INTARY,5,34)
      IF(INTARY(2).EQ.IKY42)IGO=0
      CALL RESET(IGDS2,NULL,IKY43)
      CALL RESET(IGDS1,NULL,IKY70)
      CALL MLITS(IATL,2)
      DO 1010 I=1,NT
      DO 1011 J=1,4
      ITCRT(I,J)=0
 1011 CONTINUE
 1010 CONTINUE
 1709 CONTINUE
      CALL OMIT(IGDS2,NULL,IKY41)
      CALL OMIT(IGDS2,NULL,IKY42)
      IF(ICON.EQ.1)GO TO 1710
      REP1=ITM
 1720 DO 1760 I=1,NT
      IF(EVT(I,20).EQ.1.)GO TO 1760
      DO 1759 J=1,7,2
      IF(EVT(I,J))1701,1701,1702
 1701 IF(J.NE.1)GO TO 1760
      EVT(I,9)=ICRIT(I,1)/REP1
      GO TO 1760
 1702 EVT(I,J+1)=ICRIT(I,(J+1)/2)/REP1
 1759 CONTINUE
 1760 CONTINUE
C
C     DISPLAY CRITICALITY INDEX FOR EACH ARC
C
      CALL STPOS(IGDS2,350,960)
      CALL PTEXT(IGDS2,TEXT28,17,NULL,IKY48,1,350,960)
      CALL MARK(EVT,LOC,IGDS2,NT)
      CALL EXEC(IGDS2)
      CALL MLITS(IATL,4,3)
      CALL RQATN(IATL,INTCD,2,NULL,3)
      CALL RESET(IGDS2)
      EAN=SUMM/REP1
      DEV=SQRT((SUMD-((1/REP1)*(SUMM**2)))*(1/(REP1-1)))
      ITM=REP1
      CALL PLTHIS(IGDS5,IGDS6,NULL,I2250,EAN,DEV)
```

```
      CALL MLITS(IATL,4,3,6)
      CALL RQATN(IATL,INTCD,2,NULL,3,6)
      CALL EXEC(IGDS1)
      CALL EXEC(IGDS2)
      CALL MLITS(IATL,2)
C
C     HARD OUTPUT
C
      ITAB=ITAB+1
      WRITE(6,2035)ITAB
 2035 FORMAT('1TABLE',I6)
      WRITE(6,2036)
 2036 FORMAT(' ENTRIES IN TABLE',24X,'MEAN TIME',32X,'STANDARD DEVIATION
     #')
      WRITE(6,2037)REP1,EAN,DEV
 2037 FORMAT(11X,F6.0,25X,F8.2,42X,F8.2)
      WRITE(6,2038)
 2038 FORMAT('0',19X,'UPPER',17X,'OBSERVED',17X,'PER CENT',15X,'CUMULATI
     #VE')
      WRITE(6,2039)
 2039 FORMAT(20X,'LIMIT',16X,'FREQUENCY',17X,'OF TOTAL',15X,'PERCENTAGE'
     #)
      IZ=IW-1
      PLOT(1,2)=PLOT(1,2)+THI
      TH=THI*.5
      DO 2052 I=2,IZ
      PLOT(I,2)=PLOT(I,2)+TH
 2052 CONTINUE
      PER=0.0
      DO 2041 I=1,IZ
      WRI=PLOT(I,1)*100.
      PER=PER+WRI
      WRITE(6,2040)PLOT(I,2),IHIS(I),WRI,PER
 2041 CONTINUE
 2040 FORMAT(17X,F8.1,19X,I6,19X,F6.2,19X,F6.2)
      IF(INTCD.EQ.6)GO TO 1770
      GO TO 200
 1710 REP1=REP1+TM
      ICON=0
      GO TO 1720
 1770 ICON=1
      CALL PTEXT(IGDS2,TEXT11,8,NULL,NULL,1,50,70)
      CALL PTEXT(IGDS2,TEXT16,8,NULL,NULL,1,240,70)
      CALL PTEXT(IGDS2,BLN,4,1,NULL,1,170,70)
      CALL EXEC(IGDS2)
      CALL ICURS(IGDS2,1,NULL,1)
      CALL EXEC(IGDS2)
      CALL MLITS(IATL,4,1)
```

```
      CALL RQATN(IATL,INTCD,2,NULL,1)
      CALL RCURS(IGDS2)
      CALL GSPPD(IGDS2,TIM,4,1,ITIM,1)
      CALL BCNV(TIM,TM,202,4,0)
      ITM=TM
      CALL RESET(IGDS2)
      CALL MLITS(IATL,2)
      DO 1784 I=1,NT
      DO 1783 I1=1,4
      ITCRT(I,I1)=0
 1783 CONTINUE
 1784 CONTINUE
      GO TO 1730
C
C     TERMINATE PROGRAM
C
  300 CALL MLITS(IATL,2)
      CALL TMGDS(IGDS1)
      CALL TMGDS(IGDS2)
      CALL TMDEV(I2250)
      CALL TMGSP(IGSP)
      STOP
      END


      SUBROUTINE DIST(IGDS3,IGDS4)
C
C     ENTER A DISTRIBUTION OF ACTIVITY COMPLETION TIMES
C
      COMMON/GS1/EVT,DIS,INTARY,IPT,NULL,I2250,IATL,IE,K1,K2,K3,K4,
     1INTCD
      DIMENSION YTX(5),BLK(2),TEMP(2),TEX1(2),TEX2(2)
      DIMENSION EVT(50,20),DIS(50,20,3),INTARY(10),IPT(50,4),NULL(1)
      DATA YTX/'0.0','.25','.50','.75','1.0'/,DASH/'-'/,XI/'I'/,T/'|'/,
     1BLK/'    ','    '/,TEMP/'    ','    '/
      DATA TEX1/'DETE','CT X'/,TEX2/'DETE','CT Y'/
      CALL STPOS(IGDS4,512,975)
      CALL PTEXT(IGDS4,TEX1,8,NULL,IKE1,1,512,975)
      CALL EXEC(IGDS4)
C
C     DRAW AXIS FOR PLOT
C
      CALL STPOS(IGDS3,56,30)
      CALL PLINE(IGDS3,1004,30)
      CALL STPOS(IGDS3,56,30)
      CALL PLINE(IGDS3,56,913)
      DO 310 I=1,5
      LY=I*220-190
```

```
      CALL STPOS(IGDS3,14,LY)
  310 CALL PTEXT(IGDS3,YTX(I),3,NULL,NULL,1,14,LY)
      DO 320 I=1,21
      LY=I*44-14
      CALL STPOS(IGDS3,56,LY)
  320 CALL PTEXT(IGDS4,DASH,1,NULL,NULL,1,56,LY)
      DO 330 I=1,21,2
      LX=9+I*47
      CALL STPOS(IGDS3,LX,30)
  330 CALL PTEXT(IGDS4,XI,1,NULL,NULL,1,LX,30)
      DO 335 I=2,20,2
      LX=9+I*47
      CALL STPOS(IGDS3,LX,30)
  335 CALL PTEXT(IGDS4,T,1,NULL,NULL,1,LX,30)
  336 CALL STPOS(IGDS3,19,10)
      CALL PTEXT(IGDS3,BLK,6,1,NULL,1,19,10)
      CALL STPOS(IGDS3,940,10)
      CALL PTEXT(IGDS3,BLK,6,11,NULL,1,940,10)
      CALL SLPAT(IGDS4,1)
      CALL EXEC(IGDS3)
      CALL EXEC(IGDS4)
C
C     ENTER EXTREMES OF X-AXIS
C
      CALL ICURS(IGDS3,1,NULL,1)
      CALL EXEC(IGDS3)
      CALL MLITS(IATL,4,1)
      CALL RQATN(IATL,INTCD,2,NULL,1)
      CALL GSPRD(IGDS3,TEMP,6,1,ITERM,1)
      CALL STPOS(IGDS3,IGDS3,19,10)
      CALL PTEXT(IGDS3,TEMP,6,NULL,NULL,1,19,10)
      CALL EXEC(IGDS3)
      CALL BCNV(TEMP,DL,202,6,1)
      CALL RCURS(IGDS3)
      CALL ICURS(IGDS3,11,NULL,1)
      CALL EXEC(IGDS3)
      CALL RQATN(IATL,INTCD,2,NULL,1)
      CALL GSPRD(IGDS3,TEMP,6,1,ITERM,11)
      CALL STPOS(IGDS3,940,10)
      CALL PTEXT(IGDS3,TEMP,6,NULL,NULL,1,940,10)
      CALL EXEC(IGDS3)
      CALL BCNV(TEMP,DU,202,6,1)
      CALL RCURS(IGDS3)
      CALL MLITS(IATL,2)
C
C     CALCULATES AND LABELS DIVISIONS ON X-AXIS
C
      DA=DU-DL
```

```
      DB=DL
      D=DA/10.0
      DO 341 I=2,10
      DL=D+DL
      CALL BCNV(DL,TEMP,102,6,1)
      LX=19+(I-1)*92
      CALL STPOS(IGDS3,LX,10)
  341 CALL PTEXT(IGDS3,TEMP,6,I)
      CALL EXEC(IGDS3)
C
C     PLOT DISTRIBUTION
C
      IE=1
      DIS(K3,1,1)=0.0
      DIS(K3,1,3)=0.0
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      CALL SALRM(I2250)
      IXB=INTARY(8)
      X=IXB-56
      DIS(K3,1,2)=(X/945)*DA+DB
      IYB=30
  350 CALL STPOS(IGDS4,512,975)
      CALL PTEXT(IGDS4,TEX1,8,NULL,IKE1,3,512,975)
      CALL MLITS(IATL,4,0,2)
      CALL ROATN(IATL,INTCD,2,INTARY,0,2,34)
      IF(INTCD.EQ.-1)GO TO 500
      IF(INTCD.EQ.2)GO TO 351
      IE=IE+1
      IXA=INTARY(8)
      X=IXA-56
      DIS(K3,IE,2)=(X/945)*DA+DB
      CALL STPOS(IGDS4,512,975)
      CALL PTEXT(IGDS4,TEX2,8,NULL,IKE1,3,512,975)
      CALL ROATN(IATL,INTCD,2,INTARY,34)
      IYA=INTARY(9)
      Y=IYA-30
      DIS(K3,IE,1)=Y/880
      DIS(K3,IE,3)=0.0
      CALL STPOS(IGDS3,IXB,IYB)
      CALL PLINE(IGDS3,IXA,IYA)
      CALL EXEC(IGDS3)
      IXB=IXA
      IYB=IYA
      IF(IE.EQ.20)GO TO 500
      GO TO 350
  351 CALL RESET(IGDS3,1)
      CALL MLITS(IATL,2)
      DO 352 I=1,IE
```

```
      DIS(IPT(K1,K4),I,1)=0.0
  352 DIS(IPT(K1,K4),I,2)=0.0
      GO TO 336
  500 CALL MLITS(IATL,2)
      RETURN
      END


      SUBROUTINE MEAN(KP,DIS,TMN)
C
C     CALCULATE THE MEAN OF A DISTRIBUTION
C
      DIMENSION DIS(50,20,3)
      I=1
      TMN=0.
 1201 I=I+1
      TMN=((DIS(KP,I,2)+DIS(KP,I-1,2))*.5)*(DIS(KP,I,1)-DIS(KP,I-1,1))+
     1TMN
      IF(DIS(KP,I,1).LT.1.0)GO TO 1201
      RETURN
      END
C


      SUBROUTINE RAND
C
C     GENERATE RANDOM NUMBERS BETWEEN 0 AND 1
C
      COMMON/B/IX,IY,R
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 R=IY
      R=R*.4656613E-9
      RETURN
      END


      SUBROUTINE SETTE(KP,R,TE)
C
C     SET TE USING SEQUENTIAL SEARCH
C
      COMMON/GS1/EVT,DIS,INTARY,IPT,NULL,I2250,IATL,IE,K1,K2,K3,K4,
     1INTCD
      DIMENSION EVT(50,20),DIS(50,20,3),INTARY(10),IPT(50,4),NULL(1)
      IUP=2
      ILO=1
  701 IF(DIS(KP,IUP,1).GE.R)GO TO 720
```

```
      IUP=IUP+1
      ILO=ILO+1
      GO TO 701
  720 X=(R-DIS(KP,ILO,1))/(DIS(KP,IUP,1)-DIS(KP,ILO,1))
      TE=(DIS(KP,IUP,2)-DIS(KP,ILO,2))*X+DIS(KP,ILO,2)
      RETURN
      END


      SUBROUTINE PLTHIS(IGDS5,IGDS6,NULL,I2250,EAN,DEV)
C
C     PLOT A GRAPH OF COMPLETION TIMES
C
      COMMON/GS2/PLOT,YMAX,DEXT,REXT,TLO,THI,IW,ITM,LM,IHIS,IOX,IOY,IUX,
     1IUY,NPTS,IGDS
      DIMENSION IHIS(50),PLOT(50,2),NULL(1),STEX1(4),STEX2(4),STEX4(5),
     1TM(2)
      DATA STEX1/'THIS',' ANA','LYSI','S'/,STEX2/'LAST',' ANA','LYSI',
     1'S'/,STEX3/'MEAN'/,STEX4/'STAN','DARD',' DEV','IATI','ON'/
      NPTS=IW
      S=ITM
      DO 1410 I=1,IW
      Y=IHIS(I)
      PLOT(I,1)=Y/S
 1410 CONTINUE
      W=IW
      DEXT=TLO
      T2=THI*.5
      REXT=THI*W+TLO
      PLOT(1,2)=DEXT
      PLOT(IW,2)=REXT
      JR=IW-1
      IF(JR.LE.1)GO TO 1425
      PLOT(2,2)=DEXT+THI+T2
      IF(JR.EQ.2)GO TO 1425
      DO 1420 I=3,JR
      PLOT(I,2)=PLOT(I-1,2)+THI
 1420 CONTINUE
 1425 YMAX=PLOT(1,1)
      DO 1430 I=2,IW
      IF(PLOT(I,1).GT.YMAX)YMAX=PLOT(I,1)
 1430 CONTINUE
      LM=LM+1
      IF(MOD(LM,2).EQ.1)GO TO 1450
      IF(LM.EQ.2)GO TO 1435
      CALL RESET(IGDS6)
 1435 IOX=0
      IOY=0
```

```
      IUX=1024
      IUY=512
      IGDS=IGDS6
      CALL DISPLY(NULL,I2250)
      CALL PTEXT(IGDS6,STEX3,4,NULL,NULL,1,100,930)
      CALL BCNV(EAN,TM,102,8,1)
      CALL PTEXT(IGDS6,TM,8,NULL,NULL,1,170,930)
      CALL PTEXT(IGDS6,STEX4,18,NULL,NULL,1,622,930)
      CALL BCNV(DEV,TM,102,8,1)
      CALL PTEXT(IGDS6,TM,8,NULL,NULL,1,882,930)
      CALL EXEC(IGDS6)
      CALL STPOS(IGDS6,428,970)
      CALL PTEXT(IGDS6,STEX1,13,NULL,IKY6,1,428,970)
      CALL EXEC(IGDS5)
      CALL STPOS(IGDS5,428,970)
      CALL PTEXT(IGDS5,STEX2,13,NULL,IKY5,3,428,970)
      CALL EXEC(IGDS5)
      CALL EXEC(IGDS6)
      GO TO 1460
 1450 CALL RESET(IGDS5)
      IOX=0
      IOY=512
      IUX=1024
      IUY=1024
      IGDS=IGDS5
      CALL DISPLY(NULL,I2250)
      CALL PTEXT(IGDS5,STEX3,4,NULL,NULL,1,100,930)
      CALL BCNV(EAN,TM,102,8,1)
      CALL PTEXT(IGDS5,TM,8,NULL,NULL,1,170,930)
      CALL PTEXT(IGDS5,STEX4,18,NULL,NULL,1,622,930)
      CALL BCNV(DEV,TM,102,8,1)
      CALL PTEXT(IGDS5,TM,8,NULL,NULL,1,882,930)
      CALL PTEXT(IGDS5,STEX1,13,NULL,IKY5,1,428,970)
      IF(LM.EQ.1)GO TO 1455
      CALL EXEC(IGDS6)
      CALL STPOS(IGDS6,428,970)
      CALL PTEXT(IGDS6,STEX2,13,NULL,IKY6,3,428,970)
      CALL EXEC(IGDS6)
 1455 CALL EXEC(IGDS5)
 1460 RETURN
      END

      SUBROUTINE DISPLY(NULL,I2250)
C
C     DRAWS  GRAPH
C
      COMMON/GS2/PLOT,YMAX,DEXT,REXT,TLO,THI,IW,ITM,LM,IHIS,IOX,IOY,IUX,
```

```
     1IUY,NPTS,IGDS
      DIMENSION PLOT(50,2),NULL(1),DD(2),IHIS(50)
      DATA TXO/'0.0'/,DASH/'-'/,DD/'    ','    '/,T/'|'/
      CALL SGDSL(IGDS,IOX,IOY,IUX,IUY,0,0,1024,1024)
      CALL SDATL(IGDS,0,0,1024,1024)
C     DRAW AXIS
      IXSC=1024/(IUX-IOX)
      IYSC=1024/(IUY-IOY)
      CALL STPOS(IGDS,56,30)
      CALL PLINE(IGDS,1004,30)
      CALL STPOS(IGDS,56,30)
      CALL PLINE(IGDS,56,918)
C
C     LABEL Y-AXIS
C
      CALL PTEXT(IGDS,TXO,3,NULL,NULL,1,0,50)
      CALL BCNV(YMAX,DY,102,4,2)
      CALL PTEXT(IGDS,DY,4,NULL,NULL,1,0,910)
      CALL PTEXT(IGDS,DASH,1,NULL,NULL,1,56,910)
      NLAB=(IUY-(IOY+176))/(28*IYSC)
      IF(NLAB.LE.2)GO TO 1321
      DINC=YMAX/(NLAB+1)
      ISP=880/(NLAB+1)
      DY=0.0
      DO 1320 I=1,NLAB
      JY=I*ISP+30
      DY=DY+DINC
      CALL BCNV(DY,EY,102,4,2)
      CALL PTEXT(IGDS,EY,4,NULL,NULL,1,0,JY)
      CALL PTEXT(IGDS,DASH,1,NULL,NULL,1,56,JY)
 1320 CONTINUE
C
C     LABEL X-AXIS
C
 1321 NLAB=(IUX-IOX)/(90*IXSC)
      CALL BCNV(DEXT,DD,102,6,1)
      CALL PTEXT(IGDS,DD,6,NULL,NULL,1,19,10)
      NLAB=NLAB-1
      DINC=(REXT-DEXT)/NLAB
      DTEXT=DEXT
      INC=945/NLAB
      DO 1330 I=1,NLAB
      KX=I*INC+8
      DTEXT=DTEXT+DINC
      CALL BCNV(DTEXT,DD,102,6,1)
      CALL PTEXT(IGDS,DD,6,NULL,NULL,1,KX,10)
      KX=KX+48
      CALL PTEXT(IGDS,T,1,NULL,NULL,1,KX,30)
```

```
 1330 CONTINUE
      DIF=REXT-DEXT
      IF(DIF.EQ.0.)GO TO 1360
      UINC=945./DIF
      IF(YMAX.EQ.0.0)GO TO 1355
 1335 IYA=(PLOT(1,1)*880.)/YMAX+30.
      IXA=56
      DO 1350 I=2,NPTS
      CALL STPOS(IGDS,IXA,IYA)
      IYB=(PLOT(I,1)*880.)/YMAX+30.
      IXB=(PLOT(I,2)-DEXT)*UINC+56.
      IYA=IYB
      IXA=IXB
      CALL PLINE(IGDS,IXB,IYB)
 1350 CONTINUE
      GO TO 1355
 1360 UINC=945/NPTS
      GO TO 1335
 1355 CALL EXEC(IGDS)
      RETURN
      END


      SUBROUTINE CRIT(ITCRT,LOC,IGDSX,EVT,NT)
C
C     DRAWS A LINE ALONG ARCS ON CRITICAL PATH
C
      DIMENSION ITCRT(50,4),LOC(50,2),EVT(50,20)
      DO 1560 I=1,NT
      IF(EVT(I,20).EQ.1.)GO TO 1560
      DO 1559 J=1,4
      IF(ITCRT(I,J).NE.1)GO TO 1559
      LX=LOC(I,1)-44
      LY=LOC(I,2)+2
      LX1=LX+4
      LY1=LY
      CALL STPOS(IGDSX,LX,LY)
      IF(EVT(I,1))1510,1510,1520
 1510 LX=LX-60
      LX2=LX
      LY2=LY
      GO TO 1530
 1520 LX=LOC(EVT(I,J*2-1),1)-2
      LX2=LX+4
      LY=LOC(EVT(I,J*2-1),2)+2
      LY2=LY
 1530 CALL PLINE(IGDSX,LX,LY)
      CALL STPOS(IGDSX,LX1,LY1)
```

```
      CALL PLINE(IGDSX,LX2,LY2)
      CALL EXEC(IGDSX)
 1559 CONTINUE
 1560 CONTINUE
      RETURN
      END

      SUBROUTINE MARK(EVT,LOC,IGDS2,NT)
C
C     PRINTS DATA ON ARCS IN PERT NETWORK
C
      DIMENSION TN(2),EVT(50,20),LOC(50,2)
      DO 1660 I=1,NT
      IF(EVT(I,20).EQ.1.)GO TO 1660
      DO 1659 J=1,7,2
      IF(EVT(I,J))1601,1601,1602
 1601 IF(J.NE.1)GO TO 1660
      LX=LOC(I,1)-132
      IF(LX.LT.0)LX=0
      LY=LOC(I,2)+10
      CALL BCNV(EVT(I,9),TN,102,7,2)
      CALL STPOS(IGDS2,LX,LY)
      CALL PTEXT(IGDS2,TN,7,NULL,NULL,1,LX,LY)
      CALL EXEC(IGDS2)
      GO TO 1660
 1602 LX2=LOC(EVT(I,J),1)
      LY2=LOC(EVT(I,J),2)
      LX1=LOC(I,1)
      LY1=LOC(I,2)
      LX=(LX1+LX2)/2-42
      LY=(LY1+LY2)/2+10
      CALL BCNV(EVT(I,J+1),TN,102,7,2)
      CALL STPOS(IGDS2,LX,LY)
      CALL PTEXT(IGDS2,TN,7,NULL,NULL,1,LX,LY)
      CALL EXEC(IGDS2)
 1659 CONTINUE
 1660 CONTINUE
      RETURN
      END

      BLOCK DATA
C
      COMMON/GS1/EVT,DIS,INTARY,IPT,NULL,I2250,IATL,IF,K1,K2,K3,K4,
     1INTCD
      DIMENSION EVT(50,20),DIS(50,20,3),INTARY(10),IPT(50,4),NULL(1)
      DATA DIS/3000*0.0/
```

```
         END
//LINK.SYSIN DD *
         INCLUDE SYSLIB(IHCGSP03)
//GO.FT10F001 DD UNIT=(2250-1)
//GO.SYSIN DD *
```

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13. ABSTRACT

A system for PERT analysis using Monte Carlo methods to estimate project completion times was designed using a 2250 Display Unit operating on an IBM 360/67 computer. The user enters the PERT network and the distributions of activity times by using the light pen on the 2250 Display Unit.

After the computer performs the analysis, the probability of being on the critical path is shown for each arc in the network and a histogram of project ompletion times is displayed. The user may then modify the network and run another analysis.

A discussion of the difference between this Monte Carlo PERT analysis and the usual PERT analysis and details of the implementation is included, along with operating instructions for the program. A user with no programming experience on the 2250 Display Unit can utilize the program by following the operating instructions.

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